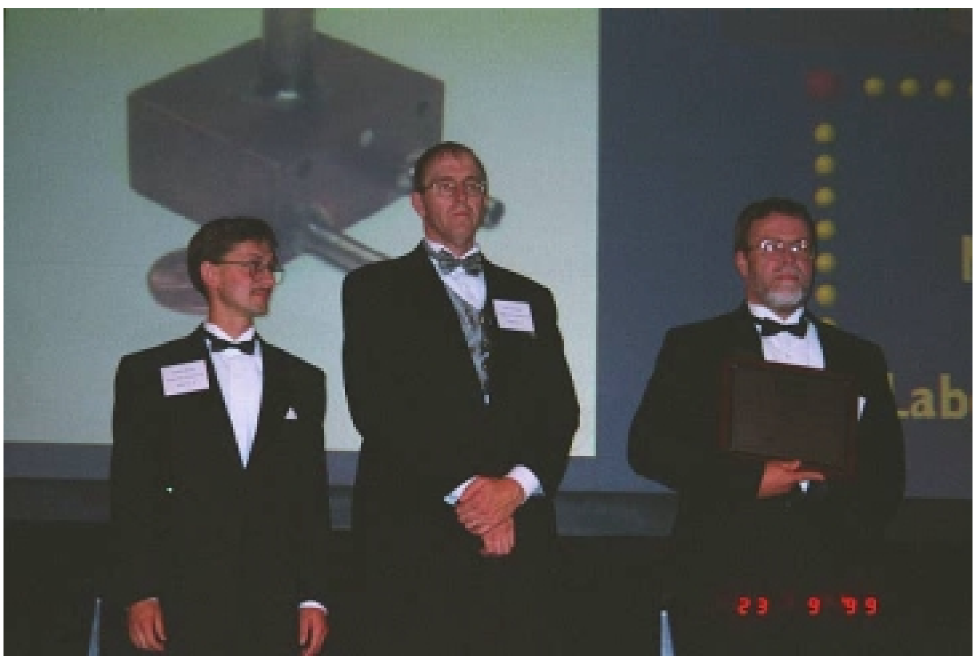
1999 Winner

MicroHeater



PNNL

Pacific Northwest National Laboratory

Operated for the U.S. Department of Energy
by Battelle

The MicroHeater's small, modular, high-capacity combustion system enables an entirely new range of products. The technology is an essential factor in two innovative systems that are in high demand: personal, portable heating and heat-pump cooling units, and modular heating units for buildings.

Construction workers, fire-fighters, rescue workers, and ground troops working in freezing weather need personal portable heating units that will enable them to move freely and safely. The MicroHeater is already the basis of the first such unit, now being supplied to civilian and military markets by a domestic manufacturer. The MicroHeater technology also permits miniaturization of heat pump-based cooling systems. These systems are a critical factor in making sealed protective gear usable for prolonged periods—as when dealing with chemical warfare products, biological toxins, and hazardous waste cleanup. The worldwide market for the personal, portable heater is estimated to be 500,000 units per year, while the cooling market is estimated to be 300,000 units per year. This represents annual sales of $850 million.

The modular MicroHeater units provide efficient baseboard and inline water heating for industrial and non-industrial buildings at low cost and with low emissions. A homeowner converting to MicroHeater baseboard heating from a conventional electrical heating system would save approximately $300/year in energy costs alone. ***Even more significant, from an individual and a national perspective, are the 25%-45% reductions in energy losses from furnaces and ducting.*** No other systems approach MicroHeater's flexible, modular design, low emissions rate, and economical, high-production fabrication method. The potential market for the MicroHeater in baseboard heating is very large—1 to 10 million units per year.

MicroHeater Features

The MicroHeater was created by Kevin Drost, Bob Wegeng, Jerry Martin, Chuck Call, Peter Martin, and Kriston Brooks. It is a small, lightweight combustor, approximately the size of a deck of playing cards, weighing about 0.2 kg (5 oz.). Because it is 10 times smaller and lighter than conventional combustors, the MicroHeater is being used to fire the first personal heater that can be carried as a backpack (Figure 1). The combustor can be adapted to heat pump-based personal, portable cooling systems that are heat actuated. It's also an efficient source of indoor heating. The MicroHeater can produce 30 W of thermal energy per square centimeter of external combustor area. One module can power a personal, portable heater for 8 hours on little fuel or provide instantaneous in-line water heating; an array of modules will heat a house efficiently and reduce ducting and zoning thermal energy losses by 45%.

This technology is the first application of enhanced microscale heat and energy mass-transfer to a combustion process. MicroHeater's thin, stacked metal sheets form tiny channels through which hot water passes, heating the entire unit. The stacked sheets provide a large surface area in a very small space, and the microchannels minimize the amount of circulating water—and thus, the amount of fuel—needed to operate the MicroHeater. The design ensures MicroHeater has high combustion efficiency and low emissions. Innovative fabrication techniques resolve technical problems related to mass-producing small units with microchannel elements, and permit cost-effective microchannel manufacture. MicroHeater achieves its small size, affordability, and very low levels of emissions by relying on high rates of heat and energy mass transfer through specially fabricated microchannels. It is the first device of its kind, and offers unique and much-needed opportunities for miniaturizing heating and heat pump-based devices.

The MicroHeater is built using laminate fabrication, an innovative method for forming microchannels. Thin metal strips (100 to 200 microns thick) are chemically etched to form patterns. As shown by the schematic in Figure 2, these thin metal strips are stacked to form channels and bonded to form a monolithic block of metal with embedded microchannels for both combustion products and cooling water. The result is very deep and narrow microchannels, which are preferred for heat transfer (Figures 3 and 4). The fabrication method is well adapted to mass production and permits easy manufacture of customized modular units. Other lithographic or mechanical methods for machining similar microchannels, such as LIGA, require highly sophisticated manufacturing devices, are expensive, and are not well suited either to customization or rapid mass production.

The combustor is externally supplied with a mixture of gaseous fuel (such as natural gas or butane) and air, which passes through a sintered metal plate that distributes the fuel/air mixture and acts as a flame holder. Combustion occurs directly above the sintered metal plate, and the combustion products exit through an array of microchannels, each measuring approximately 200 microns. The combustion products are rapidly cooled, and the thermal energy is transferred to a second array of microchannels that contain water. Mass transfer of thermal energy heats the water as the combustion products cool, generating either hot water or steam. This flows through the MicroHeater unit, and is then returned to the core to be reheated.

The MicroHeater is rugged and safe to operate. Constructed of copper and stainless steel, it will withstand high temperatures and rough handling. The flame is entirely enclosed within the combustor, and the unit itself never becomes warmer than the temperature it generates (that is, if a personal heater is set at 98°F, the unit will not become hotter than 98°F). When applied to portable applications such as manportable heating and cooling, the MicroHeater can operate without any electric power. The pressure drop in the MicroHeater is so low that the pressure available in fuels such as butane and propane is sufficient to entrain (drag in) combustion air in a jet ejector, avoiding the need of any sort of fan. Emissions from the MicroHeater meet California clean air standards for stationary boilers.

Compelling Performance

The MicroHeater is unique as a combustor for personal, portable heating packs and heat pump-based coolers. Applications for small combustion systems include gas-fired baseboard heaters for space conditioning, hot water heating for hydronic heating systems and in-line gas fired hot water heaters. Conventional central gas-fired equipment exists for these applications, therefore a comparison can be based on comparing the MicroHeater used for heating hot water for a hydronic heating system with a conventional natural gas fired hot water heater or boiler. Several current heating devices are shown in the following table: Bosch, Myson and Valiant supply in-line hot water heaters; Glowcore provides high efficiency boilers; and Valiant provides cast-iron boilers.

Note that the ***MicroHeater provides a radical reduction in weight and size compared to current boiler technology—even compact instantaneous hot water heaters—while achieving an efficiency higher than all but the highest efficiency boiler.*** The production cost of the MicroHeater is heavily dependent on production rates. A cost of $20 to $40/kW would be attainable in the estimated production runs of more than 100,000 units per year.

Manu-Facturer	Type	Energy Input (kBtu/h)	Energy Efficiency	Volume per Energy Unit Output (l/kW)	Weight per Energy Unit Output (kg/kW)	Cost per Energy Unit Output ($/kW)	Competitive Advantage
MicroHeater	**Micro-channel**	**4 to 120**	**80-85%**	**0.04**	**0.2**	**20-40**	**Efficient, modular, expandable, extremely light weight, very small**
Bosch	In-line heater	117	77%	2.2	0.6	20	Not modular, lower efficiency
Myson	In-line heater	100	76%	3.5	0.8	17	Not modular, lower efficiency
Glowcore	Boiler	150	94%	N/A	1.7	43	Not modular, expandable, or portable; no instantaneous heat
Valiant	Boiler	80	84%	11.4	3.9	51	Not modular, expandable, or portable; no instantaneous heat
Valiant	Boiler	120	83%	9.7	3.0	39	Not modular, expandable, or portable; no instantaneous heat

Smaller by a factor of 10 compared to conventional heaters, the MicroHeater can produce 30 W of thermal energy per square centimeter of external combustor area, with a combustion efficiency of 78% to 85%. Its design makes it much more adaptable than larger combustors. MicroHeater is modular; each unit is about the size of a deck of cards. Modules can be used alone, or combined to meet specific heating needs. An 18-cm^3 (7-$in.^3$), 1-module MicroHeater combustion and a small fuel supply unit would, for example, generate 8 hours of thermal energy to operate a personal heating pack for a rescue worker in subzero temperatures. A 20-module array of 25-cm by 25-cm by 2-cm unit (about the size of a box of cereal) produces approximately 20 kW of thermal energy, sufficient to heat most homes.

MicroHeater does not rely on heavy, costly batteries, bulky external generators, or expensive electrical power for its heat source. Instead, it operates on natural gas. It is so efficient that a canister of gas the size of a soda can will power a personal, portable heating pack for a day. Emissions are very low, meeting or exceeding the California Emissions Control standards for stationary heaters.

Unlike conventional combustion systems, the MicroHeater system can be easily scaled down to 1 to 4 kBtu/h heating rates. ***This is an important attribute for customizing combustion capacity for personal climate control systems and other microsystems.*** Its modularity makes MicroHeater unusually efficient in a wide range of industrial and non-industrial heating applications, such as in-line instantaneous hot water heating. Modularity also ensures that the per-kilowatt cost of the MicroHeater is very reasonable and nearly constant, even for very small systems. In contrast, reducing the size of a conventional system, even if such a feat were possible, would be difficult and costly.

Attractive Applications

The MicroHeater is currently being prepared for deployment in two areas: portable energy systems, where size and weight are critical; and distributed space heating and cooling, where the availability of inexpensive modular combustion systems are critical. The principal near-term applications of the MicroHeater are presented below.

- **Personal, portable heating systems.** There is a significant consumer and military market for a manportable heating system. A system with dimensions of 3 cm by 3 cm by 2 cm, providing 250 W, has been demonstrated and shipped to a client for testing.

- **Personal, portable cooling systems using heat pumps.** The military needs a manportable cooling system for soldiers wearing chemical and biological warfare clothing. The heat-actuated systems that are being developed for this application are not feasible without a lightweight, compact combustion system. The MicroHeater combustor would measure 4 cm by 5 cm and provide approximately 500 W. A cooling system that incorporates the MicroHeater is being developed for the Defense Advanced Research Projects Agency (DARPA).

- **Modular gas-fired baseboard heaters for residential space heating.** Current baseboard heaters use electricity, which is 3 to 5 times more expensive than natural gas. The MicroHeater provides the combustion system that would allow the commercialization of a gas-fired baseboard heating system. The MicroHeater's compact, low-cost, natural gas combustion system makes it possible to assemble modular, gas-fired baseboard heaters. Assuming a residence with an annual heating load of 5000 kWh, the conversion from electricity to natural gas would save a homeowner $300/year. Baseboard heating systems have many advantages compared to central heating. They do not require ducting and allow zoning (i.e., the ability to separately control the temperature of different zones of a residence). Losses in ducting systems can easily account for 25% of the thermal energy leaving a furnace, and ducting in a typical home can cost up to $3,000. Studies have shown that the zoning inherent in baseboard heating can further reduce energy consumption by 20%. Using flexible natural gas lines with quick-connect and disconnect fittings developed by the Gas Research Institute, the modular gas-fired baseboard heater could be used for both new construction and retrofits.

Other important applications of the MicroHeater are presented below.

- **Heat source for automotive cooling** - A gasoline-fired MicroHeater will allow the cooling system to function when the engine is not operating. The MicroHeater is being evaluated by automobile companies as a heat source for a heat-actuated (absorption cycle) automotive or truck cooling system.

- **Process heating of microchemical systems** - PNNL researchers are developing a range of microchannel reactors for portable and distributed fuel processing, particularly hydrogen production for automotive fuel cells. The MicroHeater is the heat source for these endothermic microchannel reactors.

- **In-line gas-fired hot water heating** - Electrical in-line hot water heaters are available but electricity is expensive. The MicroHeater can provide gas-fired hot water heating, reducing the cost of in-line water heating.

The use of microchannel combustion and heat transfer can allow the development of very small combustion systems. Pacific Northwest National Laboratory is currently extending the MicroHeater concept to very small sizes (.1 to 1-watt output). This work is being funded by the DARPA and will lead to on-chip process heating and power generation for Microelectromechanical (MEMS) devices. The typical fuels used for combustion store 100 times more energy per kg than a battery. An on-chip combustion system coupled with an electric power generator will allow an autonomous MEMS device to operate for extended time periods without battery replacement.

Publications

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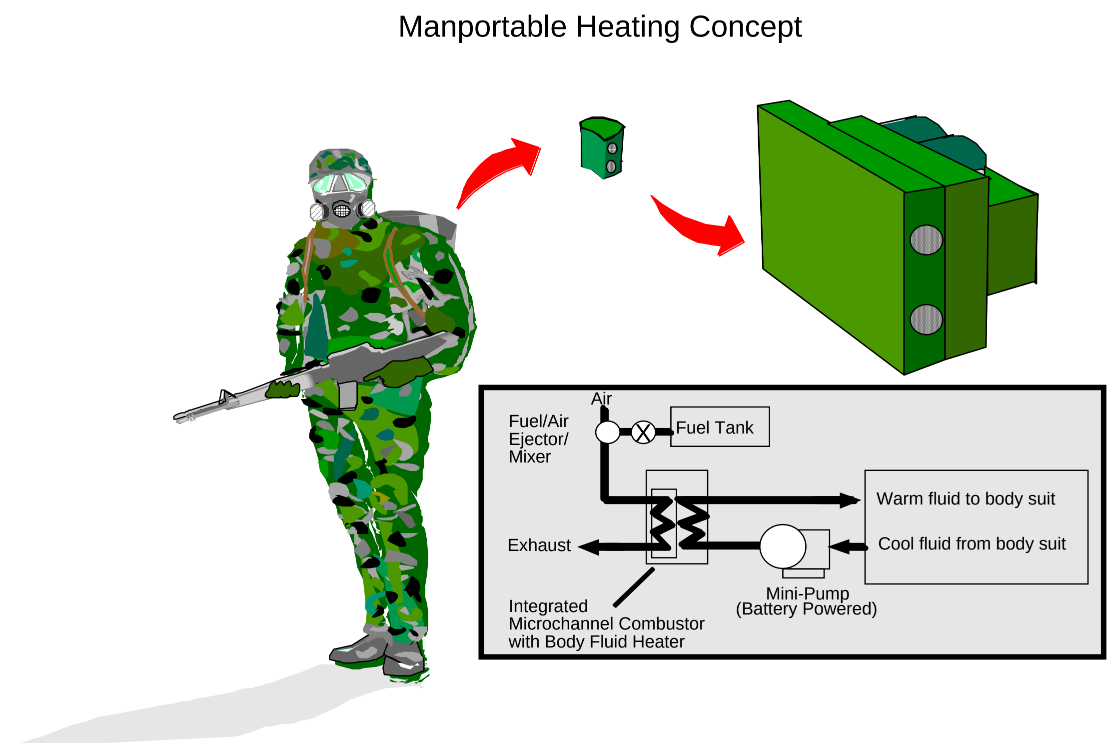


Figure 1. The MicroHeater microscale combustor is an efficient, lightweight heat generator for a personal, portable heating pack. Eight hours of fuel are contained in a soda-can sized gas container.

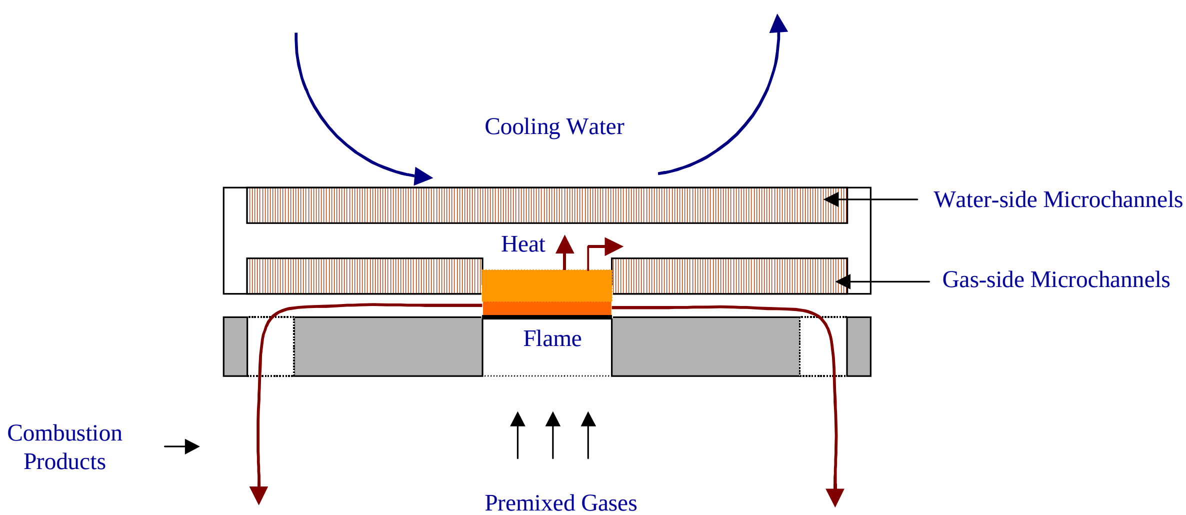


Figure 2. Schematic of the MicroHeater

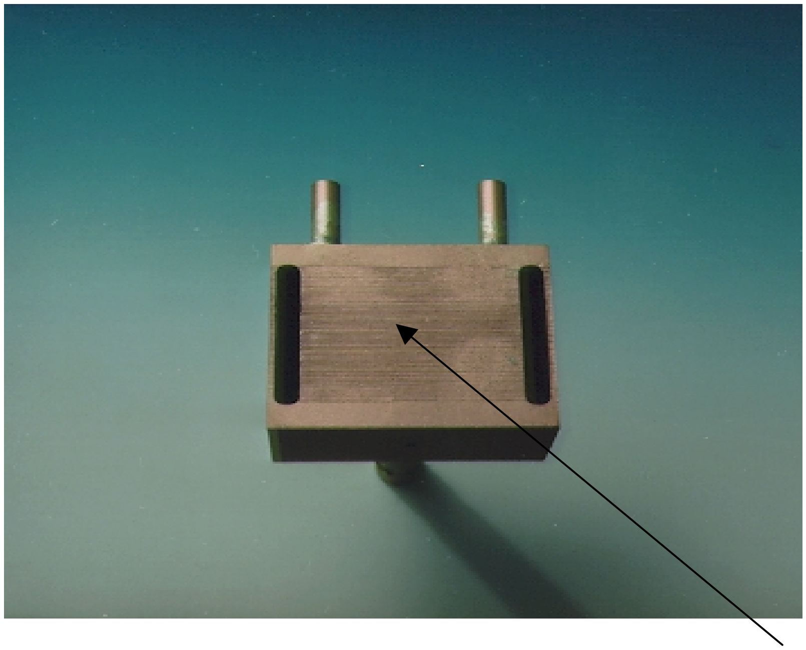
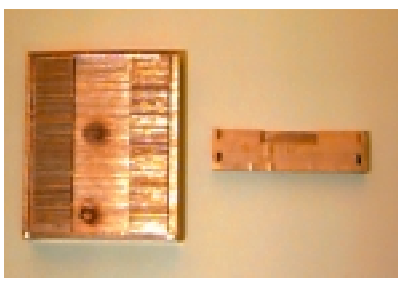


Figure 3. Reverse view of MicroHeater combustion unit, showing microchannels

Laminated copper combustor showing shims and microchannels



- Uses OFHC 0.005”-thick copper
- Integrates bottom plate with HX plate
- 187 fins and 188 spacers/unit
- Overall dimensions after lamination: 2” x 3/8” x 1 3/4”

Microchannel thickness to scale

- 8-mil-thick Cu shims

Figure 4. Copper sheet components, joined and laminated