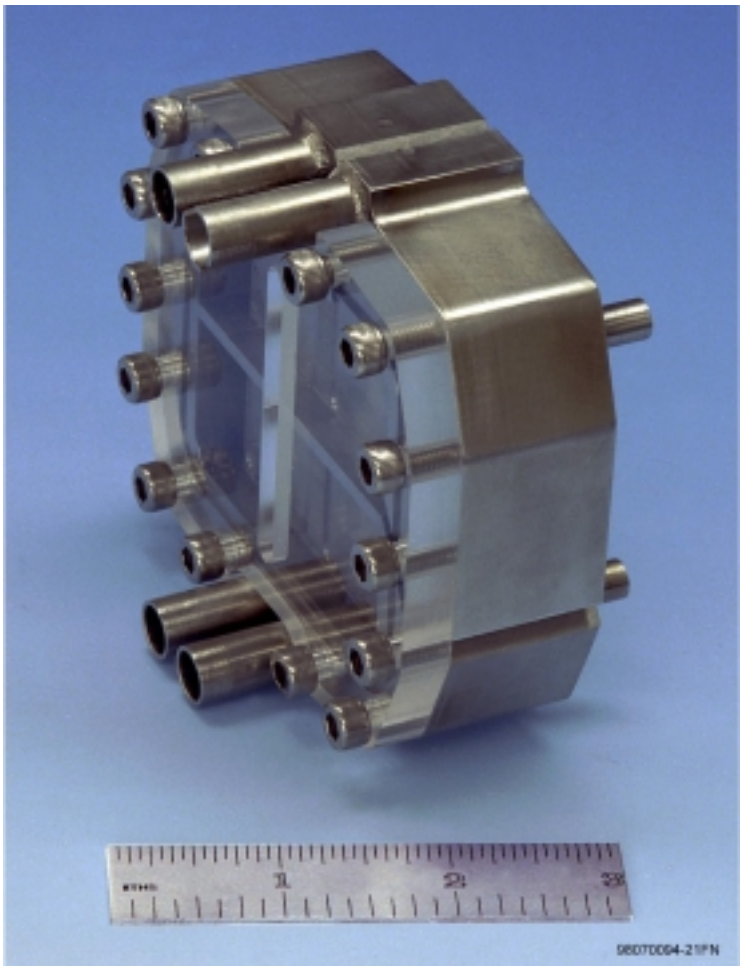
1999 Winner

Compact Microchannel Fuel Vaporizer

PNNL

Pacific Northwest National Laboratory

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



The Compact Microchannel Fuel Vaporizer (CMFV) is a breakthrough in miniaturizing and intensifying process technology, which, when applied with the other reactors, will enable the fuel processing system to be small enough for automotive or portable applications. The CMFV's small size helps overcome one of biggest practical problems of fuel cell-powered automobiles—fitting the device in the available space. Consumer acceptance demands that new technology must not take up current trunk or passenger space. The CMFV will easily fit into an automobile engine compartment.

The CMFV's microchannel heat exchangers allow for a fuel processor/fuel cell system suitable for powering an automobile. Conventional shell-and-tube boiler technology cannot meet the needs of portable power applications because the design does not scale down efficiently to the size required for portable applications. The CMFV's microchannel design meets those needs.

Consumers and our society will realize major benefits from the widespread use of fuel cell-powered vehicles. Vehicles using the fuel processor/fuel cell system, of which the CMFV is a key part, will have system efficiencies exceeding 40% to 45%, compared with efficiencies of 20% to 25% for internal combustion engines. The emission of carbon dioxide will drop by more than 50% per mile traveled because of improved system efficiency. Automobiles represent approximately 31% of all CO_2 emissions in the United States.[(a)] This clean technology will also virtually eliminate carbon monoxide and nitrous oxide from vehicle operations. Other environmentally damaging wastes associated with motor vehicles, such as crankcase oil and antifreeze, will become things of the past.

CMFV Features

Fuel cells are a high-efficiency, low-emission alternative to the internal combustion engine for automobiles, but they run on hydrogen. No infrastructure currently exists to deliver either gaseous or liquid hydrogen to fuel cell-powered automobiles, but a gasoline-distribution infrastructure exists. The Compact Microchannel Fuel Vaporizer (CMFV) is a key component in a system that will allow users to continue to use gasoline as fuel, and then will enable gasoline to be converted on-board to hydrogen. The technology can also be used to convert other liquid fuels, such as diesel and methanol.

Until now, existing fuel processing technology could not be scaled down to a small enough size for automotive applications—the fuel vaporization component was one of the roadblocks to downsizing. The CMFV removes this roadblock and brings the fuel cell-powered automobile a significant step closer to reality.

[(a)] Energy Information Administration. 1995. *Emissions of Greenhouse Gases in the United States 1987-1994*. DOE/EIA-0573(94), U.S. Department of Energy, Washington, D.C.

This new and innovative fuel processing technology is small, efficient, modular, lightweight, and potentially inexpensive, making it ideal for automotive or portable applications. The CMFV (see photo at front and Figure 1) is 9 x 10 x 3.8 cm in size (the volume of a soda pop can) and weighs 4 lb. A unit this size can vaporize 260 mL/min of gasoline, enough to feed a fuel processor that can support a 50-kW fuel cell. Its size and weight are dramatically reduced compared with conventional heat exchangers, which when operating at this capacity are more than an order of magnitude larger!

Fuel cell exhaust is about 8% hydrogen. The CMFV makes efficient use of this waste hydrogen stream by combusting the hydrogen from a fuel cell anode to provide the heat needed to vaporize the liquid gasoline. The only reliable way to combust the hydrogen is with a catalyst. Conventional systems use large pellets of catalyst having numerous microstructures with tortuous dead-end diffusion paths through which molecules must transport to reach an active catalyst site. In contrast, the CMFV uses an engineered monolithic palladium catalyst featuring small pores through which the gas flows (see Figures 2 and 3). Molecules have to diffuse a distance between 10 to 100 microns versus 1,000 to 10,000 microns for pellets.

The engineered catalysts, when used in conjunction with integral microchannel heat exchangers, significantly reduce heat transport limitations that increase the size of conventional technology. This reduction is achieved by using the microchannels to break up a single fluid stream into many parallel small streams, each with a flow width of several hundred microns. These parallel streams are exposed to a larger surface-area-per-unit-volume in the microchannels than a single stream of equal volume passed through a much larger tube (on the order of centimeters) used in a conventional heat exchanger. Therefore, the fluid flowing in the microchannels comes in contact with more hot surface area than a tube of the same volume. In addition, small channels decrease convective heat transfer resistance, improving the effectiveness of the heat exchange surface area so that the heat transfer rate *per unit area* is more than an order of magnitude higher than in conventional heat exchangers. When using a microchannel heat exchanger, the combination of high-surface-area-per-unit-volume design with greatly enhanced heat transfer per unit area allows the heat in the oxidized hydrogen/air stream to be efficiently transferred to the incoming liquid gasoline (see Figure 4).

The simple linear scaling laws of the CMFV add to its flexibility. Additional vaporizer units are simply added in parallel to achieve the desired performance.

A schematic of the CMFV operation is shown in Figure 5. The catalyst sits in a small well (~6.3 mm deep). The combustion gases (or fuel cell anode effluent) enter through the top plate, react in the monolith, and travel down through a hole in the footer to the header of the heat exchanger plate below. The heat exchanger section has back-to-back microchannels. As the hot combustion product gases flow through the microchannels, heat is conducted to the microchannels on the backside, which has countercurrent gasoline flow. The microchannels on the combustion gas side are 0.25-mm wide and 4.6-mm deep, and the fins (i.e., microchannel walls) are 0.25-mm thick. The microchannels and fins on the gasoline side are the same width but 2.5 mm deep. (See figures for a more detailed description on the microchannel technology in fuel processing.)

CMFV Performance Advantanges

The Compact Microchannel Fuel Vaporizer is unique. It is therefore without any direct competitors at this time. However other fuel processing hardware is in the development stage at the present time. The CMFV is compared with several other technologies in the following table.

Feature	CMFV	Other Emerging Technologies[a]	Conventional Boiler Technology	Competitive Advantage
Hardware Volume	**0.35 liters**	3 liters	>10 liters	One-tenth the size
Weight	**1.8 kg (4 lb)**	>10 lb	>50 lb	Lightweight—twice as light as nearest competitor; portable
Operation Under Varying Load	**Response time of seconds**	Response time of minutes	Response time of minutes	Responsive to variable automotive load requirements
Heat Flux per Unit Hardware Volume (W/cm^3)	**11.5**	~1.2	0.1 to 1.0	10 times more heat per unit hardware volume
Development Stage	**Demonstrated full-scale[b] device, two units shipped[c]**	Under development	In use	Innovative new technology
Fabrication Method	**Low-cost laminate fabrication**	Conventional extrusion, machining, and welding	Conventional extrusion, machining, and welding	Low labor cost, consistent quality

(a) All work is in the development stage; information is proprietary; estimates are provided where possible based on our knowledge of research activities.
(b) Supports a 50-kW fuel processor/fuel cell.
(c) The CMFV is currently being integrated within the automotive fuel processor systems under development by two companies.

These comparisons to other alternatives support the following advantages of the CMFV:

- The CMFV is responsive to variations in speed and power consumption**.** In contrast, the slow-reacting boiler system requires several minutes of response time.
- The CMFV can be manufactured with automated techniques, reducing the cost per unit and ensuring a consistent quality product.
- The CMFV is smaller, cheaper, more versatile, and easier to manufacture than the competing technology.
- The CMFV has the endorsement of DaimlerChrysler Corporation and the U.S. Department of Energy's Office of Advanced Automotive Technologies

Attractive Applications

The small size of the CMFV targets portable applications, principally as a component to the fuel processing system for fuel cell-powered automobiles in place of internal combustion engines. The CMFV is currently being integrated with fuel processing systems developed by two industry leaders.

A CMFV-supplied fuel processing system could be used in many 50-kW portable applications, such as off-road and recreational vehicles, quiet powerboats, and aircraft.

The CMFV can be applied to fuel cell applications where size and weight are a concern. Power supplies for remote locations (e.g., research station at the South Pole, spacecraft) are potential users of this technology.

Publications

Tonkovich, A.Y., J. L. Zilka, Y. Wang, M. J. LaMont, S. Fitzgerald, D. VanderWiel, and R. S. Wegeng. 1999. "Microchannel Reactors for Automotive Fuel Processors. I. Compact Gasoline Vaporization." Accepted for publication in the *Proceedings of the Third International Conference of Microreaction Technology*, April 1999, Frankfurt, Germany.

Tonkovich, A. Y., J. L. Zilka, M. J. LaMont, Y. Wang, and R. S. Wegeng. 1998. "Microchannel Reactors for Fuel Processing Applications. I. Water Gas Shift Reactor." Accepted for publication in *Chemical Engineering Science*.

Matson, D. W., P. M. Martin, A. Y. Tonkovich, and G. L. Roberts. 1998. "Fabrication of a Stainless Steel Microchannel Microcombuster Using a Lamination Process." In *Proceedings of the SPIE Micromachined Devices and Components IV Symposium*, Vol. 3514, September 1998, Santa Clara, California.

Tonkovich, A. Y., C. J. Call, D. M. Jimenez, R. S. Wegeng, and M. K. Drost. 1996. "Microchannel Heat Exchangers for Chemical Reactors." In *Proceedings of the 1996 National Heat Transfer Conference*, Houston, Texas.

Wegeng, R. S., and A. Y. Tonkovich. 1997. "Microchannel Fuel Vaporizer for Fuel Cells." In *Proceedings of the Annual Automotive Technology Development Customers' Coordination Meeting*, October 1997, Dearborne, Michigan.

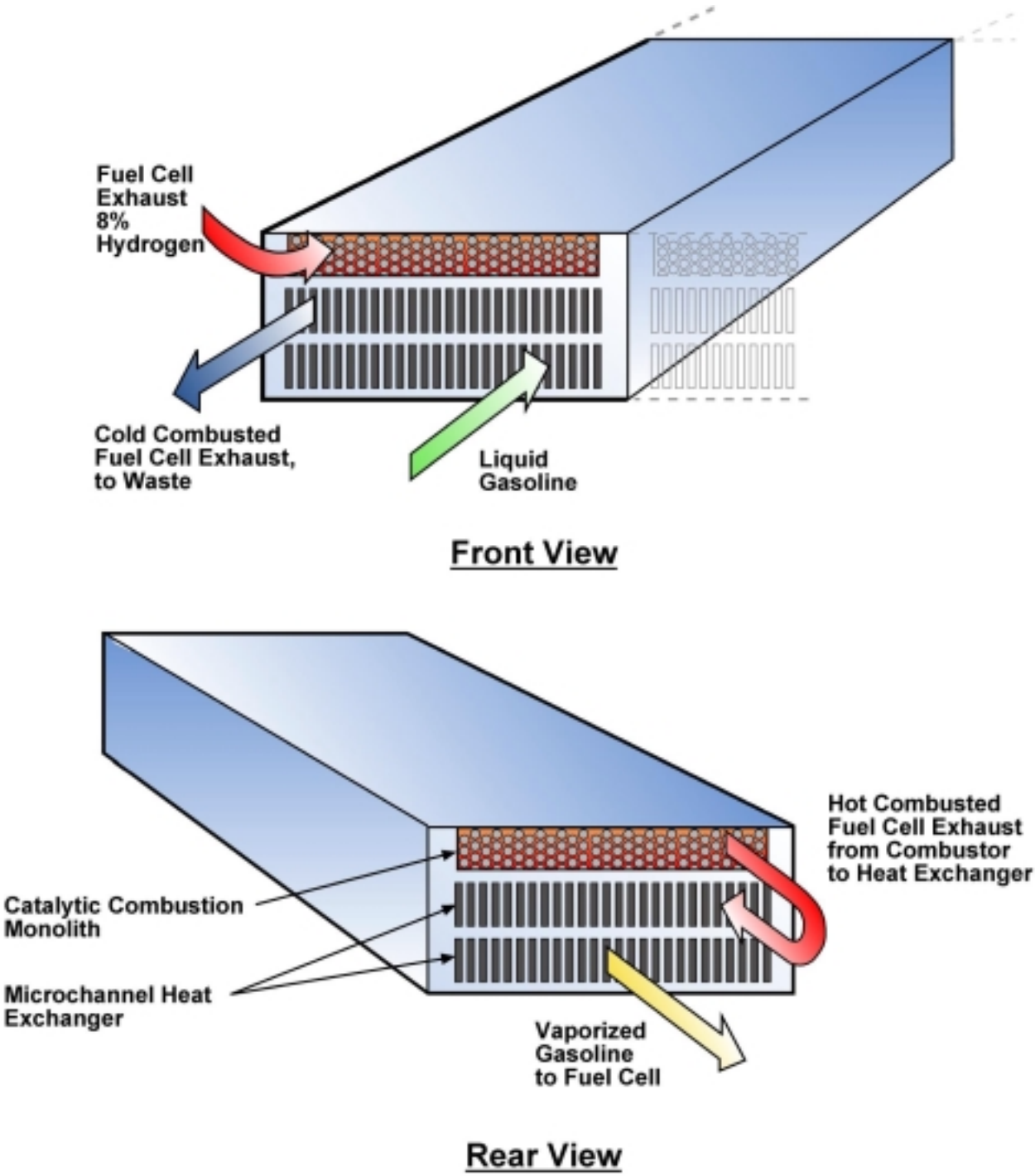


Figure 1. Compact Microchannel Fuel Vaporizer Schematic

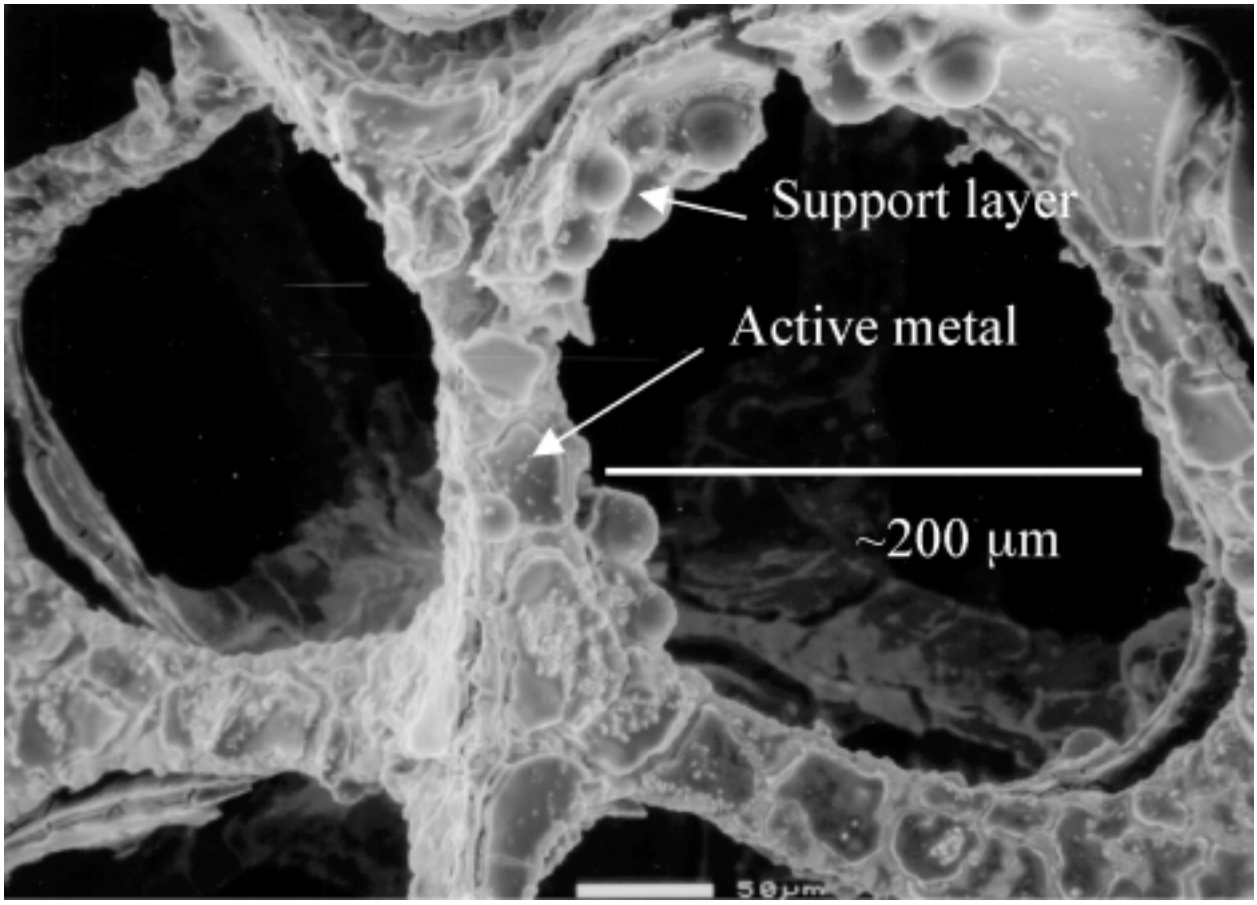


Figure 2. Pore Structure of the Compact Microchannel Fuel Vaporizer's Engineered Catalyst

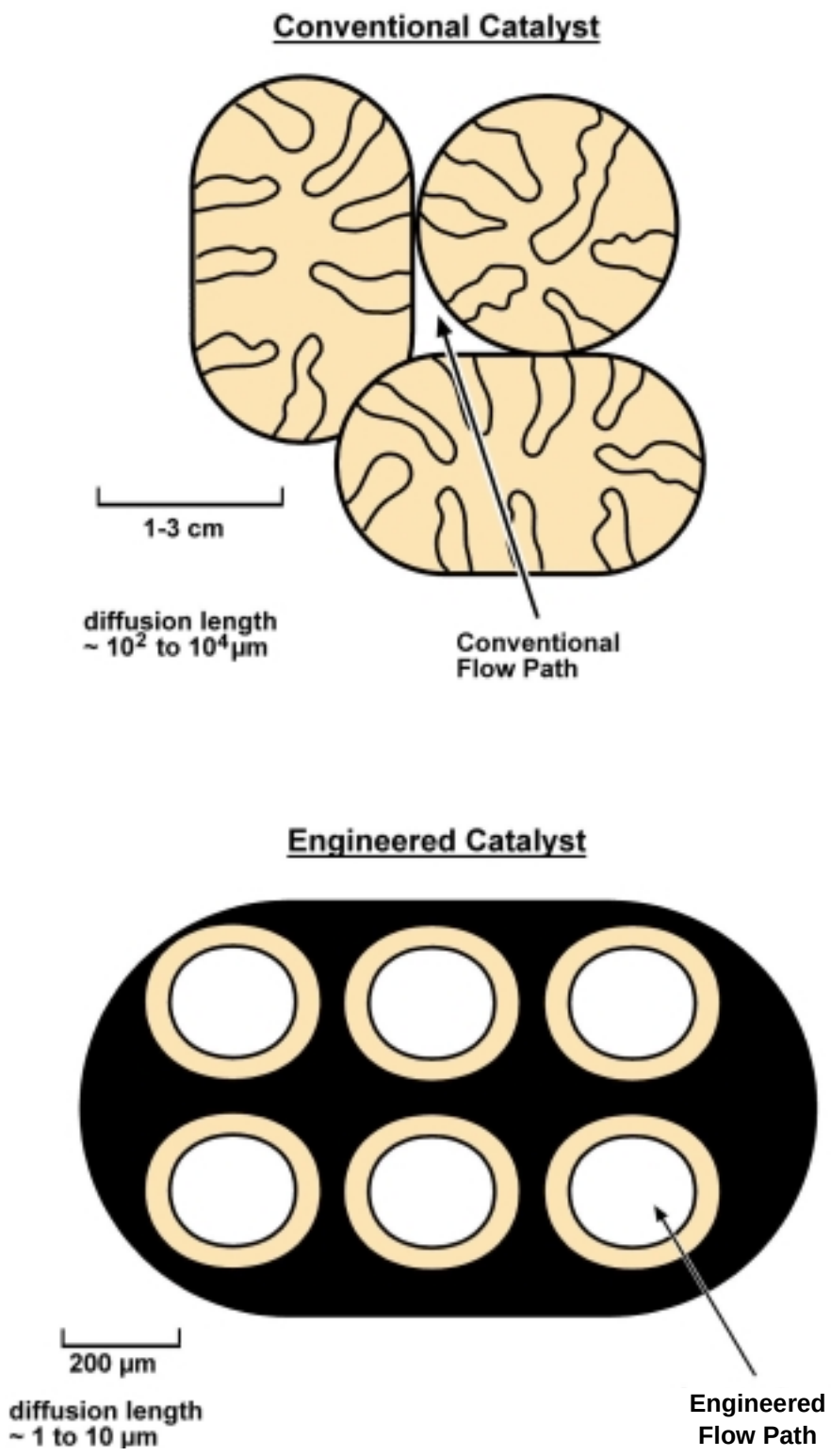


Figure 3. Conventional Versus Engineered Catalysts

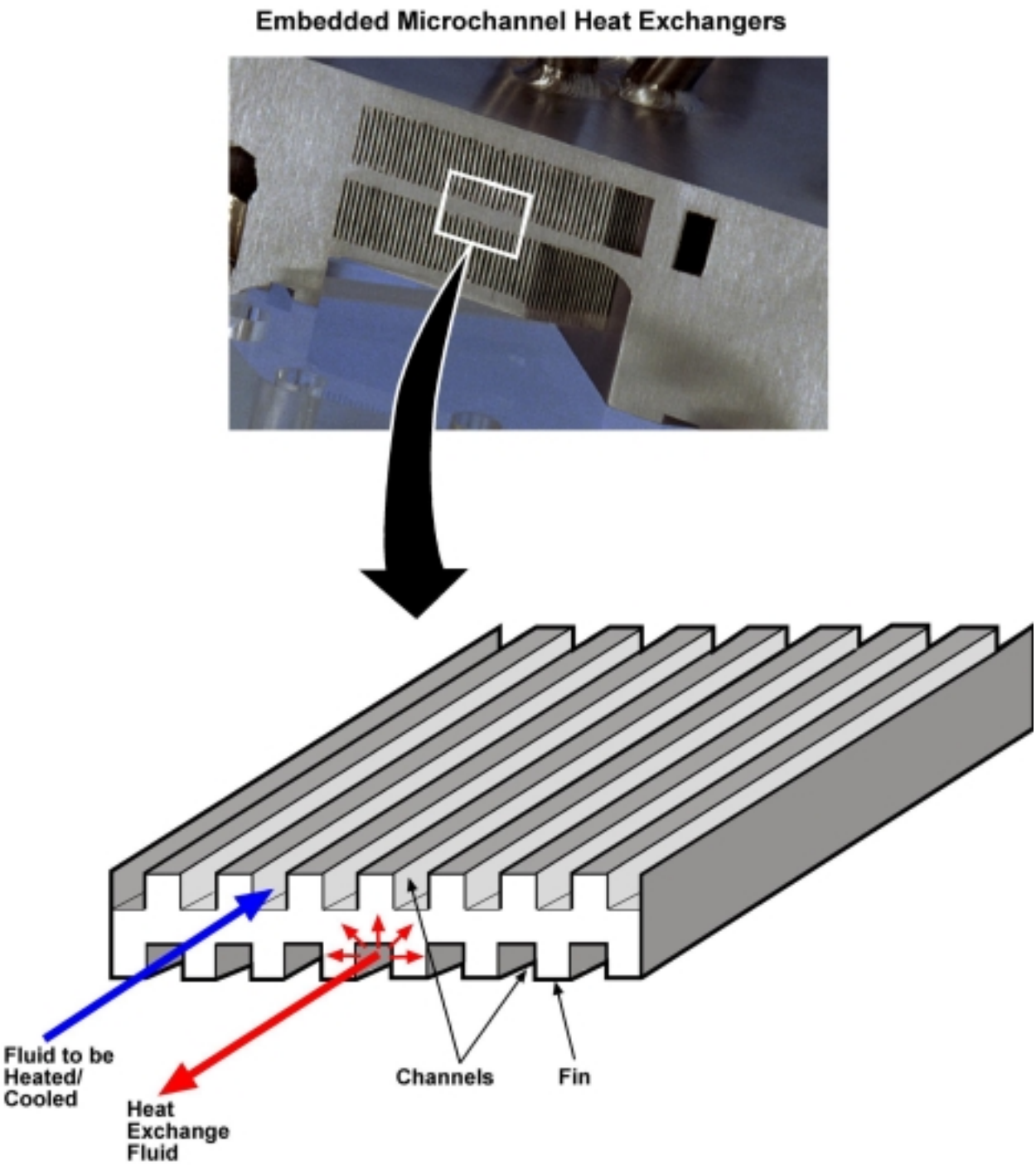


Figure 4. Schematic of Microchannel Heat Exchanger Design

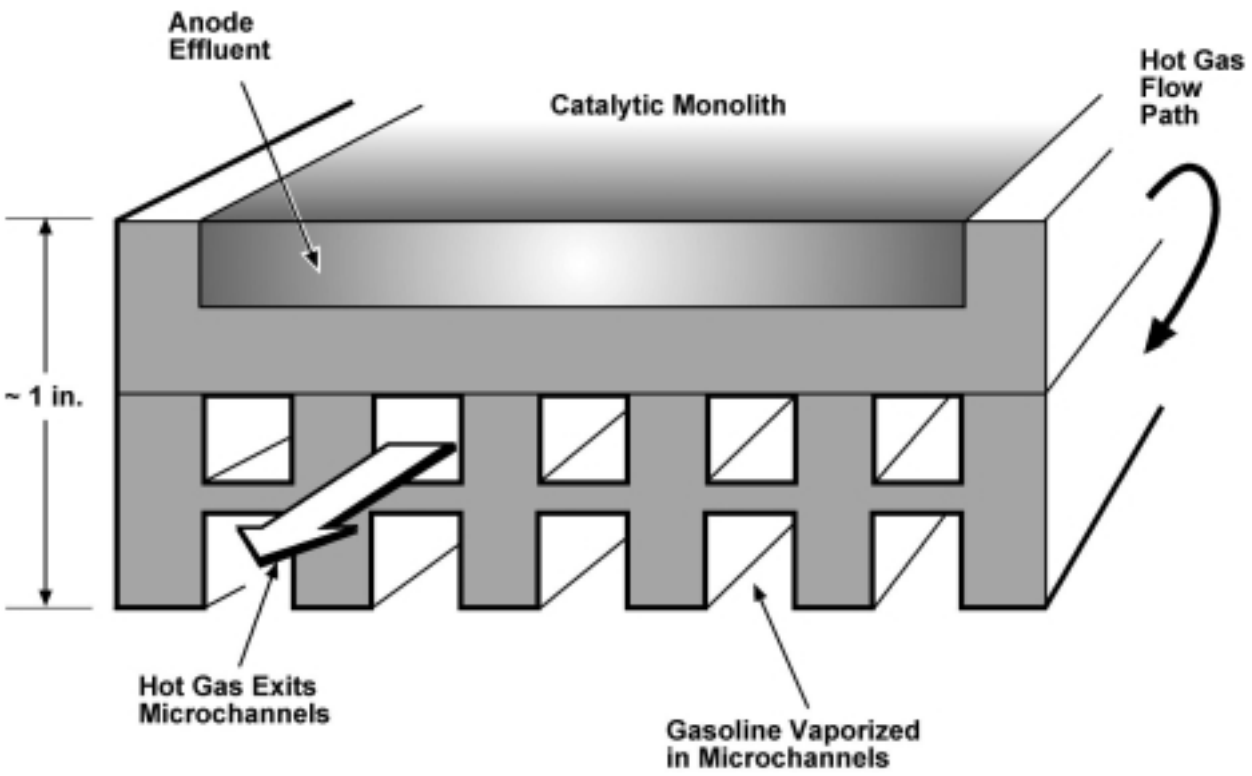


Figure 5. Schematic of Compact Microchannel Fuel Vaporizer Operation