# Development of Micro-Chemical and Thermal Systems

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## Abstract

For most of this decade, Pacific Northwest National Laboratory (PNNL) has been a pioneer in developing Micro-Chemical and Thermal Systems (MICRO-CATS™). The strategy for developing microtechnology-based components and systems includes integrating parallel efforts in directed basic research and assessing potential needs in commercial markets. The flow from basic research to development projects to final products is illustrated in Figure 1. PNNL has discipline-oriented organizations but the development of MICRO-CATS uses diverse product teams. A single product team may include scientists, engineers, and technicians as well as technical managers, commercialization managers, and communications experts. Microtechnology Fairs are used to promote technical exchange among team members,

**Figure 1.** Micro-Cats Web Page

communicate with other PNNL staff and management, and present capabilities and new technologies to customers. The MICRO-CATS website (http://www.pnl.gov/microcats) is an important medium for integrating teams, products, and applications.

## Microtech-Based Products

The potential exists for every chemical engineering unit operation to be miniaturized to increase process intensity. Similarly, all thermal and chemical systems can be miniaturized to increase their overall efficiency and productivity. Among these possibilities are applications demanding microtechnology-based solutions now. Therefore, PNNL invests in developing products where the following inherent microtech advantages provide a unique edge:

- Lightweight and compact
- Rapid heat and mass transport
- Extremely precise control of process conditions
- High performance (i.e., high throughput per unit hardware volume)
- Cost economies through mass production
- Available for distributed or mobile applications
- Short lead times for development and deployment.

Just as rapid advances in microelectronics have revolutionized computers, appliances, communication systems, and many other devices, PNNL's efforts in creating MICRO-CATS seek to revolutionize heat exchangers, heat pumps, combustors, gas absorbers, solvent extractors, fuel processors, and many other devices. These lightweight, compact, high-performance systems can work in many applications in transportation, buildings, military, environmental restoration, space exploration, carbon management, and industrial chemical processing.

PNNL's patented "sheet architecture" [U.S. Patent No. 5,611,214 (Issued March 18, 1997) and U.S. Patent No. 5,811,062 (Issued September 22, 1998)] provides a format for mass production of chemical and thermal systems. In addition to the "sheet architecture," PNNL has pioneered microfabrication methods for microdevices. State-of-the-art technology in conventional machining (slitting saw), photolithography, non-reactive ion etching and chemical etching, electrodischarge machining (EDM), and photoablation by excimer laser are all used in making devices from copper, aluminum, stainless steel, high-temperature alloys, plastics, and ceramic materials. Thus PNNL seeks to develop products with unique advantages in applying its "sheet architecture" and microfabrication capabilities. Two examples of this strategy won 1999 R&D 100 Awards, the Compact Microchannel Fuel Vaporizer and the Microheater. Both of these products target applications that give the microtech-based devices considerable market advantages.

The Compact Microchannel Fuel Vaporizer (CMFV) (Figure 2) is a breakthrough in miniaturizing process technology and a key component of a microchannel fuel processor that will enable fuel cell-powered vehicles. Fuel cells are a high-efficiency, low-emission alternative to the internal combustion engine and run on hydrogen. Currently, no infrastructure exists to deliver either gaseous or liquid hydrogen to fuel cell-powered automobiles, but a gasoline-distribution infrastructure does exist. The CMFV can vaporize the requisite amount of gasoline needed to power a 50-kWe fuel cell and is small enough (0.3-L) for portable or automotive applications.

The Microheater (Figure 3) is a microscale combustion system (the palm-size combustion unit weighs less than 0.2 kg [5 oz]) . It can provide heat for portable personal heating/cooling devices, indoor heating devices such as baseboard heaters, in-line water heaters, and fuel cell systems. It is 10 times smaller and lighter than conventional combustors. The Microheater can produce 30 W of thermal energy per square

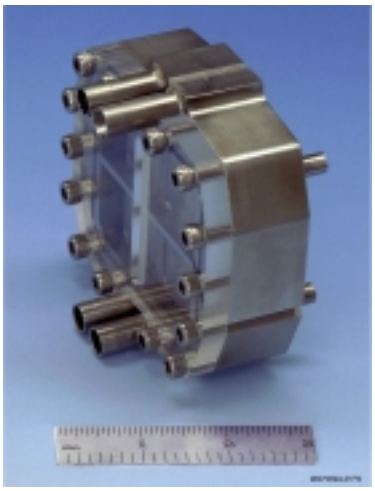

**Figure 2**. CMFV

**Figure 3**. Microheater

centimeter of external combustor area. One module can power a personal, portable heater for eight 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.

Micro- and mesoscale devices and systems progress rapidly because, unlike conventional hardware, no scale-up is required. All devices are built and tested at actual size. If a greater throughput is required, more units of identical dimensions are added in parallel. This means that during product development the setup, testing, and turnaround times are very small compared with conventional technology development.

## Needs-Driven R&D

PNNL's approach to creating new microtech-based products is to solve problems for our customers. Our promise is, *"Microtechnology doesn't work for us until it works for you."* Once an opportunity for a new product is identified, we ask, "What basic research is needed to make the concept workable?" The answers to this question determine the capabilities and technologies needed to produce workable microscale and mesoscale devices and systems. As an example, consider a customer who wants to decarbonize hydrocarbon fuels. What research might be needed to develop compact fuel conversion hardware? Figure 4 depicts some of the basic technology and science that could be conducted. To separate the carbon and hydrogen, catalytic processes are needed. Biocatalysts might be used, so high activity would be important. Chemical catalysts would require the development of engineered catalyst supports and the ability to produce engineered catalyst materials. Finally, flow conditions in the microchannels would require the understanding of phase changes and surface fouling plus the ability to simulate heat transfer and fluid flow phenomena. Simultaneous research in these areas would support the development of a microtech-based device for decarbonizing hydrocarbon fuels.

In MICRO-CATS development, basic work is done in four main areas: 1) microsystems science, 2) microchemical systems, 3) microthermal systems, and 4) microfabrication. These efforts, along with certain support such as microelectronics, provide the components for building microtech-based devices.

**Microsystems science** focuses on the study and modeling of surface effects on the flow and reactions in microchannels. The research projects below reflect this thrust. The basic research activities were designed to promote an understanding of 1) the heat transfer and chemical processes in microchannels,

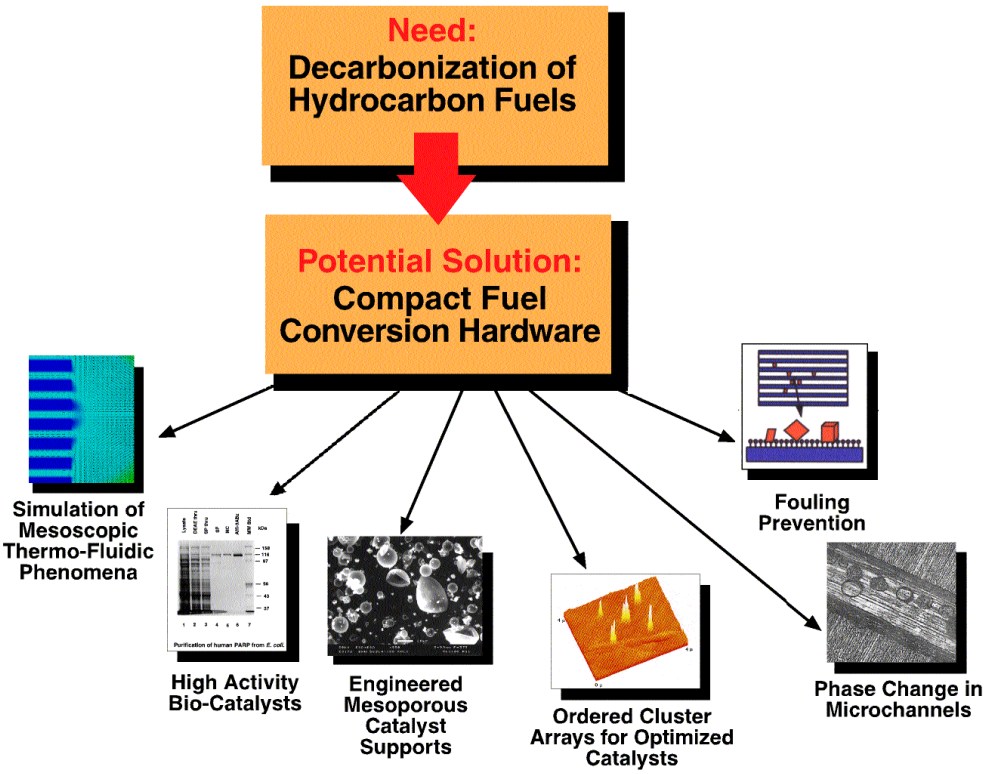


**Figure 4**. Example of Needs-Driven Science and Technology

2) approaches for making designed catalysts, 3) analytical methods for modeling the specific conditions present in microenvironments, and 4) new methods for microfabricating devices. Microsystems science research includes

- Self-assembly of highly functional molecular surfaces in microchannels
- Nanoscale fabrication for enhanced properties
- Enzymatically active surfaces
- Simulation of microfluid systems.

**Microchemical systems** focus on such devices as reactors and chemical separations. Every chemical engineering unit operation can be miniaturized to provide great advances in process intensity. Microchemical systems research includes

- Hydrocarbon processing with microsystems
- Hydrocarbon conversion
- Development and testing of microchemical separations (liquid-liquid separations)
- Microchannel reactors for automotive fuel processors.

**Microthermal systems** focus on devices such as heat exchangers and heat pumps. Microthermal systems research includes the following projects:

- Micromachined mesoscopic recuperators
- Mesoscopic pump development
- Microscale adsorption for energy and chemical systems
- Benchtop mesoscopic heat pump demonstration
- Mesoscopic heat-actuated heat pump.

**Microfabrication** focuses on developing the methods for building devices. It is necessary to be able to make devices from many materials including metals, plastics and ceramics. Examples of research for microfabrication development include

- Ceramic and plastic materials research
- High-precision rapid prototyping of microscale components.

## Science and Technology Integration

The successful development of microtech-based products requires the right combination of people, capabilities, and ideas. Moving products into the marketplace requires effective communication with potential customers. At PNNL, these tasks make use of integrated product development teams, Microtechnology Fairs, and the MICRO-CATS website. The teams combine their skills to overcome technical barriers. The Microtechnology Fairs provide the mechanism for staff to communicate their work and problems and dialogue about new ideas. The MICRO-CATS website presents PNNL's work and communicates it to those interested in our intellectual property, capabilities, and microtech-based devices.

Most of PNNL's product teams consist of 6 to 10 staff members and include scientists, engineers, technicians, and others. The teams focus completely on a single product. A core team is involved from concept development to product testing. Other members with specialty skills contribute as needed.

The Microtech Fair (Figure 5) is a unique tool that helps us communicate technical work and market microtech products. All PNNL project and product teams prepare storyboards. They are set up in one large room. Researchers bring devices and some demonstration setups. MICRO-CATS teams members, other PNNL staff and management, and customers move from display to display and discuss the concepts and applications. They ask questions. They discover ways microtechnology can solve some of their problems. The Microtech Fairs help overcome any communication barriers that might exist between various disciplines such as science and engineering. The informal one-on-one discussions make it easy for researchers to share their story. It is also easy for others to ask questions and contribute new ideas. The Microtech Fair is an ideal marketing tool because it brings the researchers, managers, customers, and commercialization staff together at the same time. Under these conditions, stronger teams are built, tough problems are solved, and healthy customer relationships result.

**Figure 5.** Microtech Fair Interactions

Developing micro-chemical and thermal systems requires diverse skills. Some staff do basic surface science studies, others create and use microfluidic simulation models, and still others build and test devices and systems. PNNL uses its MICRO-CATS website to integrate everything. This is where the complete story is available for the MICRO-CATS team, other laboratory staff, and interested parties outside PNNL. The site explains why microtechnology is powerful and points to a large range of potential applications. It communicates the products to potential users and the capabilities to those who might need them, and it presents the key technical and product line staff members. Thanks to the website, advances in MICRO-CATS become available worldwide almost as soon as they happen.