Microchannel Fuel Processing for Man Portable Power

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Abstract

Pacific Northwest National Laboratory has developed a concept for a man-portable power system that will continuously provide 10- to 100-W_e of base-load electric power for weeks or months a using microtechnology-based fuel processor. The concept and experimental progress to date are discussed.

Introduction

Compact fuel cell systems are efficient, lightweight power sources suitable for long-duration missions. Currently, the military and intelligence communities are only able to use batteries to supply electrical power for long-duration missions. Fuel cell-based energy sources have a much higher energy density than batteries. Because of the higher energy density, fuel cell-based energy systems are smaller and weigh less than conventional batteries.

The best long-duration energy source is a fuel cell that runs on hydrocarbon fuels. While hydrocarbon fuels are ubiquitous, fuel cells are becoming more prevalent. The missing technology in the fuel cell system is the unit that produces hydrogen from the hydrocarbon fuel—the fuel processor. The fuel processor produces hydrogen of sufficient quantity and purity to drive a proton exchange membrane (PEM) fuel cell and consists of a primary fuel-reforming reactor (endothermic), a water gas shift reactor (exothermic), and a method for removing carbon monoxide.

Pacific Northwest National Laboratory (PNNL) has developed a concept for a man-portable electric power system that will continuously provide 10- to 100-W_e[(a)] of base-load electric power for one month using microtechnology-based hydrogen production from liquid hydrocarbon fuels.

Projected System Configuration and Performance

Fuel cells have many features that are attractive for remote power applications, however hydrogen is required to run commercially available PEM fuel cells. Atomic hydrogen and hydrogen extracted from hydrocarbon fuels are candidate fuel sources for small PEM fuel cells. Using advanced carbon fiber materials, compressed hydrogen fuel cell systems can achieve energy densities of 1.0 kW_e-hr/kg (including the weight of the pressure reducing valves), and fuel cell/advanced metal hydride storage systems have energy densities as high as 0.5 kW_e-hr/kg. By comparison, the energy storage densities of diesel fuel and methanol are 13.2 and 5.6 kW_t-hr/kg, respectively. Current lithium polymer batteries have energy densities less than 0.3 kW_e hr/kg.

Even at 10% system efficiency, a diesel fuel-based fuel cell system has a higher energy density than a lithium polymer battery or a PEM fuel cell system that uses atomic hydrogen as the fuel. Clearly, liquid hydrocarbon fuels would be preferred for a portable power system if there were a reliable and lightweight method for extracting hydrogen from the liquid hydrocarbon fuel.

(a) The subscript e indicates that energy (W_e-hr) or power (W_e) is electrical. The subscript t implies that energy or power is thermal or chemical.

The PNNL power generation module consists of liquid hydrocarbon fuel storage, a microchannel fuel processor, and a microscale fuel cell. A lithium polymer battery could be included in the system for startup and peak power. A schematic of one packaging concept for the fuel cell-based portable power generator is shown in Figure 1.

Microchemical reactors enable miniaturization of the fuel processor because they exploit the fast intrinsic kinetics of reforming and water gas shift reactions (contact times below 100-ms), while minimizing heat and mass transfer resistances. Thermal and mass diffusion distances in microchannel reactors range from tens to hundreds of microns versus tens to hundreds of millimeters in conventional reactors. Slow heat and mass transfer dominate the operation of conventional reactor designs and thus they require multiple seconds to produce the same quantity of hydrogen for the 10-W_e fuel cell.

The microscale fuel-processor concept is based on previous research at PNNL on 10-W_e (man-portable) and 50-kW_e (automotive) fuel processors. The fuel processor includes a steam generator, recuperative heat exchangers, an integral steam reformer/combustor reactor, and a WGS reactor. A sorption unit will be added to remove residual carbon monoxide.

PNNL has shown that a microtechnology-based reactor can radically reduce the barriers to diffusion and conduction encountered in conventional reactor designs. Experimental results show that a microtechnology-based reactor can attain nearly complete conversion of liquid hydrocarbon fuel to hydrogen with a residence time between 10 and 50 ms compared with residence times that exceed 1 second in conventional reactors.

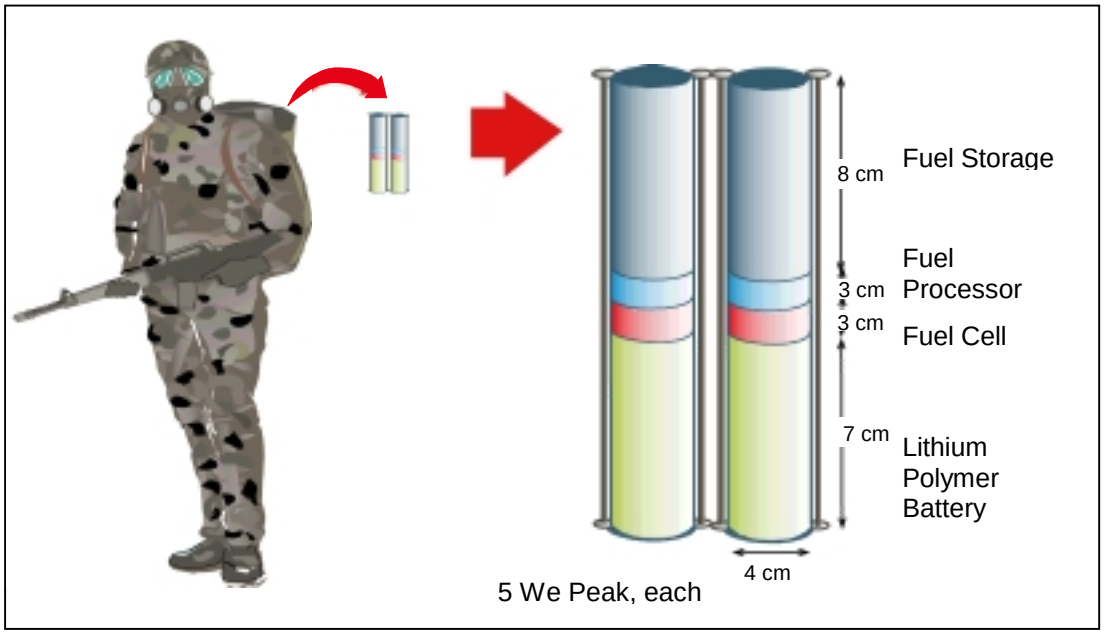

Figure 1. Conceptual Drawing of a 10 W_e Fuel-Cell-Based Portable Power System

As an example, Figure 2 shows that, for the steam reforming of butane, 100% conversion and 96% H_2 selectivity is attainable at a 25-ms contact time. At longer residence times, secondary reactions such as the formation of methane are permitted to proceed, and the hydrogen yield decreases. In addition, no coke formation was observed during the test, despite the low steam-to-carbon ratio of 1.75. The fast kinetics of the water gas shift reaction and the positive implications for microchannel WGS reactors are reported in Tonkovich et al. (1999).

The reduction of contact times in microchannel reactors leads to a reduction in reactor volume by a factor of 20 while maintaining the same productivity. Based upon experimental catalyst data, the volume of a 10-W_e fuel processor is expected to be about 8-10 cm^3.

For a one-week mission (1,680-Wh_e), a 10-W_e butane fuel-cell power system will weigh approximately 0.70 kg and have a volume of around 1 liter. Of this, the fuel weighs 0.33 kg, the fuel cell weighs 0.34 kg, and the fuel processor weighs around 30 g. The equivalent weight of lithium polymer batteries (with a generous energy density of 300 Wh_e/kg) for a 1,680-Wh_e mission is 5.6 kg. The first generation man-portable power system will have an energy density of around 2360 Wh_e/kg, or 1490 Wh_e/liter. With a high degree of thermal integration, portable fuel cell power system efficiencies as high as 40–50% may be achievable.

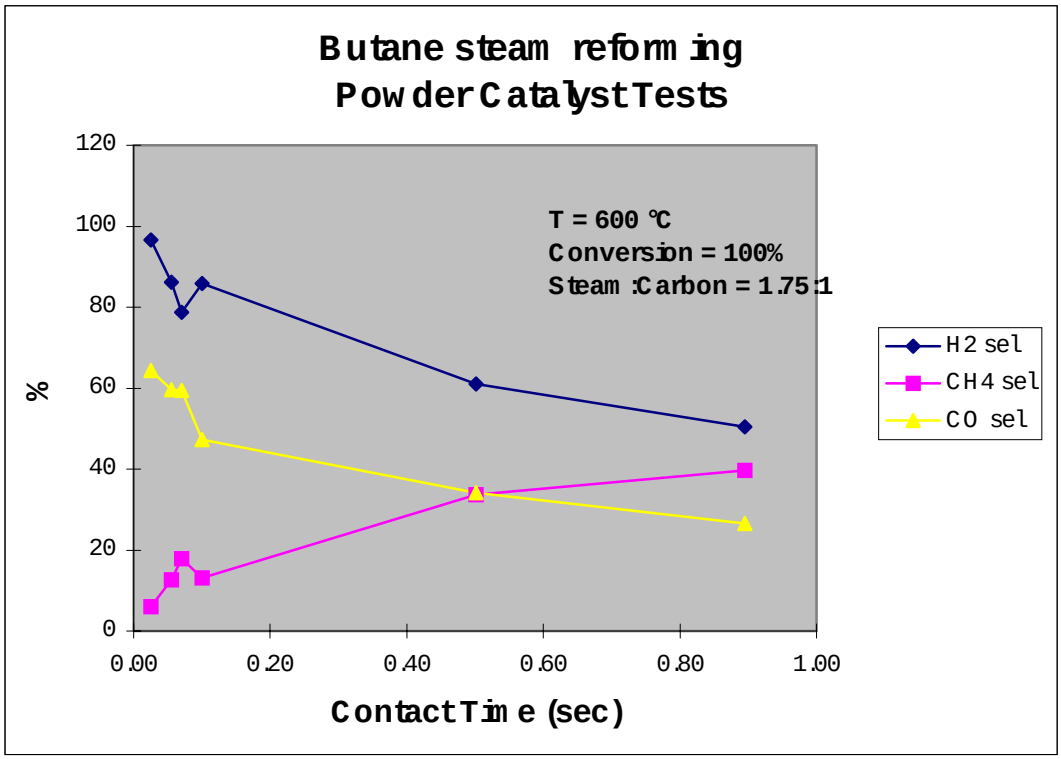

Figure 2. Butane Steam Reforming Powder Catalyst Tests. Fast kinetics implies compact processes are feasible; no coking was observed during the catalyst screening tests, despite the low steam:carbon ratio of 1.75:1.

Experimental Results

Although PNNL has demonstrated the steam reformer, vaporizers, and recuperative heat exchanger components to support development of the 50-kW_e automotive fuel processor, to date we have only demonstrated the WGS reactor at the 10-W_e man-portable scale (Figure 3). This WGS reactor has been operated for over 30 hours with carbon monoxide conversions up to 88% and CO_2 and H_2 selectivities of 100%.

Other efforts in man-portable power generation have thus far focused on the development and characterization of catalysts for the combustion of logistics fuel. Figure 4 is the 3-mm^3 combustion catalyst for a 10-W_e diesel portable power system. This catalyst could be integrated with the steam reformer to provide heat for the endothermic syngas production reaction. Lifetime test results with diesel

are shown in Figure 5. After 50 hours of testing, sulfur poisoning was not observed because of the high temperature of operation (>1000°C).

Even at modest system efficiencies, the energy density of a fuel cell-based power generation system will exceed that of batteries by a factor of eight when fuel processing is accomplished with microchannel reactors. The fast kinetics of steam reforming and WGS reactions imply that high-efficiency, high-throughput compact fuel processors are practical. At the 10-W_e scale, a microchannel WGS reactor has been demonstrated. Catalyst screening tests and automotive steam-reformer development activities suggest the same process intensification feasible for the 10-W_e steam reformer.

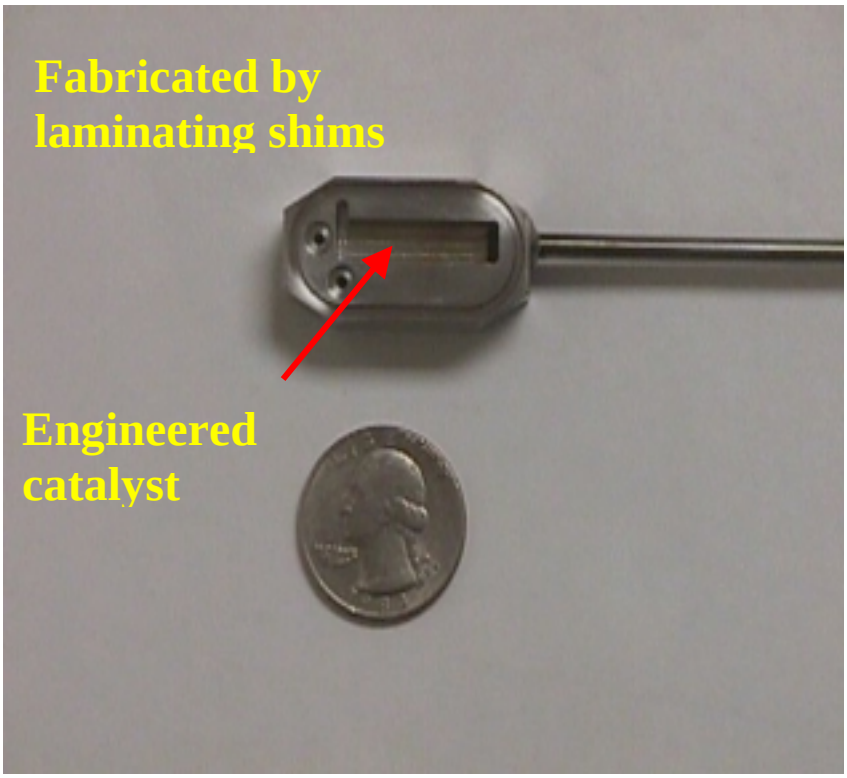

Figure 3. First Generation 10-We Man Portable WGS Reactor

Conclusions

Diesel catalytic combustion tests suggest that the combustor component of the fuel processor will have a volume of around 3-mm^3. Lifetime tests to date show the catalyst is insensitive to sulfur poisoning because of the high temperature of operation.

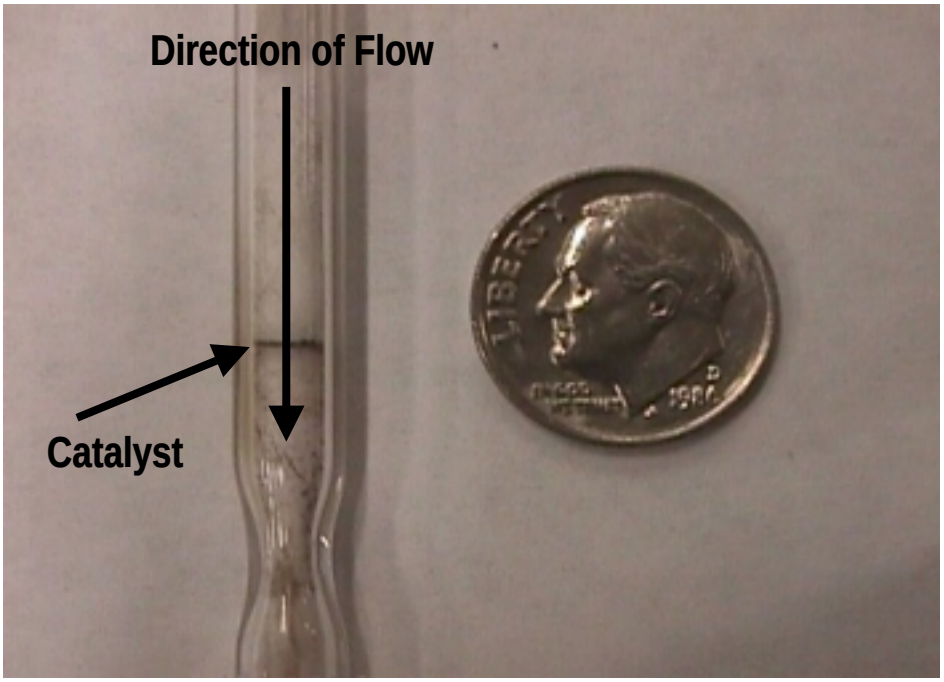

Figure 4. Engineered Catalyst for 10 W_e Logistics Fuel Combustor. Catalyst volume is around 3 mm^3.

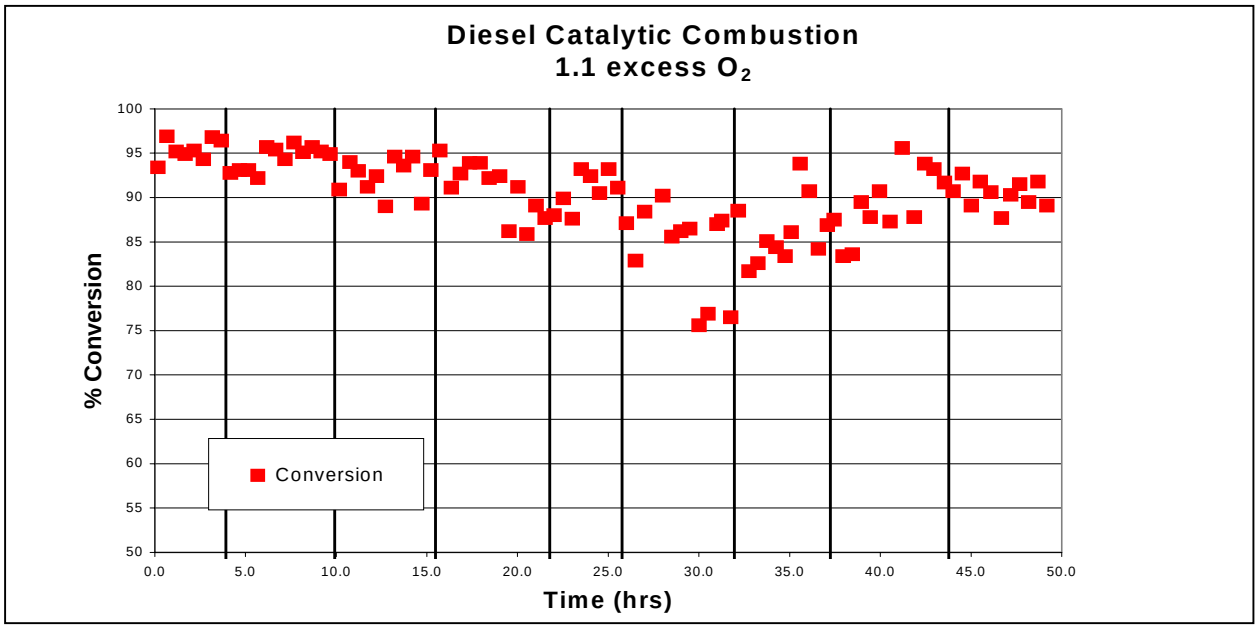

Figure 5. 10-W_e Diesel Combustion Catalyst Lifetime Tests. No sulfur poisoning was observed.

Reference

Tonkovich AY, JL Zilka, MJ LaMont, Y Wang, and RS Wegeng. 1999. "Microchannel reactors for fuel processing applications. I. Water gas shift reactor." *Chemical Engineering Science,* Vol. 54, pp. 2947–2951.