

# Compact Fuel Processor for Fuel Cell Powered Vehicles

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McDermott Technology, Inc. (MTI) and Catalytica Advanced Technologies (CAT) have teamed to develop compact fuel processors for fuel cell electric vehicle applications. Electric vehicles, powered with proton exchange membrane (PEM) fuel cells operating on reformed liquid fuels such as gasoline are one of the key applications. MTI and CAT are developing a compact, autothermal fuel processor system designed for on-board vehicle operation. As part of this development we are evaluating various catalyst compositions and performing extensive catalyst characterization testing. In addition, proprietary liquid-phase, desulfurization technologies are being developed to facilitate removal of organically bound sulfur from gasoline. This work will be followed by a 20 kWe breadboard gasoline fuel processor demonstration. The 20 kWe system will demonstrate integrated performance and provide design validation necessary for testing of a compact 50 kWe fuel processor in 2001. This paper summarizes the status of work in the emerging technology of fuel processing for fuel cell powered electric vehicles.

MTI has been active in the development of liquid fuel reforming technology for fuel cell applications since 1994 [Privette, 1996, 1998; Barringer, 1997]. In 1996, under contract to the U.S. Army Research Office (ARO) and the Defense Advanced Research Projects Agency (DARPA), MTI demonstrated the first integrated system of a planar solid oxide fuel cell stack operating on JP-8 logistic fuel. In 1998, MTI teamed with Catalytica Advanced Technologies to combine CAT's catalysis expertise with MTI's proven capability in energy system design, development, and commercialization. The combined capabilities of MTI and CAT are expected to accelerate fuel processor development, based on the recognition that catalysts provide an important key to reducing the size and maximizing the performance of the fuel processor.

The US Department of Energy (DOE) in conjunction with the Partnership for a New Generation of Vehicles (PNGV) has identified specific targets for on-board fuel processors to be met by 2004<sup>1</sup>. These targets include the following:

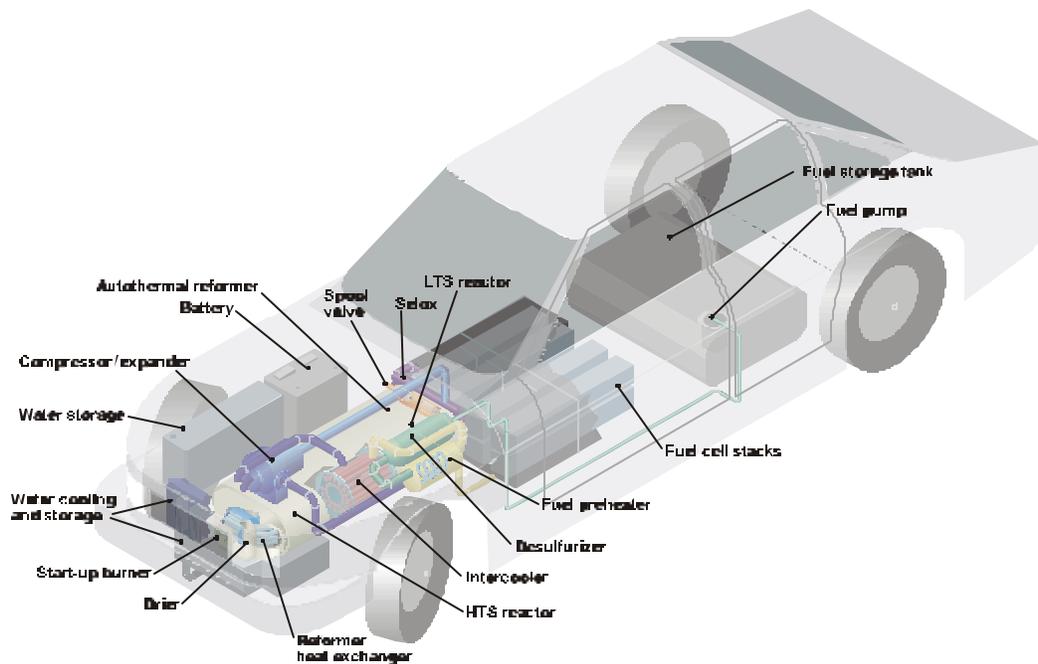
Specific Power	750 W/kg
Power Density	750 W/L
Startup to Full Power	< 1 minute
Transient Response	10 seconds (10 - 90% power)
Energy Efficiency	80%
Durability	5000 hours

The catalytic autothermal, multi-fuel processor concept in development by MTI/ CAT contains some important features that will move fuel- processing technology closer to the PNGV performance targets. Building on MTI's experience with processing sulfur-bearing liquid fuels for military fuel cell applications [Privette, 1997], the design

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<sup>1</sup> Presented at "Fuel Cell Codes and Standards Summit III", April 5-7, 1999, Washington DC.





**Figure 2. General Arrangement Drawing**

The liquid fuel desulfurizer reduces the sulfur in gasoline from 30-100 ppm to less than 3 ppm. The autothermal reformer, which operates at an average temperature of 800 C, produces a hydrogen-rich synthesis gas (syngas) from the fuel feed. A high-temperature, water-gas shift (HTS) fixed-bed catalyst (500 C) reduces the syngas CO concentration from approximately 200,000 to 20,000 ppm. The CO concentration is further reduced to 2,000 ppm in a low-temperature water-gas shift (LTS) fixed-bed catalyst operating at 200°C. The selective oxidation (Selox) unit (325 C) will reduce the remaining CO in the syngas down to less than 10 ppm.

Two major technical barriers must be overcome to enable on-board fuel processing to become practical for transportation applications 1) significant reduction in size and weight and 2) rapid start-up and transient response.

Table 1 shows the needed reductions in size and weight of individual components compared with the autothermal reformer design that MTI is developing for a Navy shipboard application. The corresponding power density and specific power for the conceptual design are 280 W/L and 285 W/kg, respectively. The PNGV targets for the same performance parameters are 750 W/L and 750 W/kg. This assumes a 50-kWe system. The concept power densities exclude the fuel tank, batteries, and water, but include controls, heat exchangers, shift reactors, CO cleanup and desulfurization. At first these densities may appear low when compared to published data on other developers fuel processors. Typically, densities around 500 W/L and 500 W/kg are reported, but those estimates usually do not include equipment for sulfur capture or selective oxidation. This is reasonable, since those systems are primarily designed for methanol.

Table 1: Component Sizes Showing Potential to Meet PNGV Goals

Component	Current Weight, kg	Concept Weight, kg	Percent Reduction	Current Volume, liter	Concept Volume, liter	Percent Reduction
Water Pump	4.54	4.54	0	1.97	0.0	100.0
Fuel Pump	2.27	2.27	0	0.98	0.0	100.0
Drier	1.13	1.13	0	0.49	0.49	0
Desulfurizer	462.66	5.90	98.7	370.43	3.20	99.1
Fuel/Water Preheater	23.00	12.82	44.3	29.62	9.27	68.7
Reformer/Heat Exchanger	137.44	36.48	73.5	88.92	13.56	84.8
Shift Reactors	96.16	22.68	76.4	246.95	29.62	88.0
Selective Oxidation	54.43	11.34	79.2	46.16	5.55	88.0
Burner Flange/Burner	17.00	17.00	0	14.46	14.46	0
Intercooler	11.34	11.34	0	7.08	7.08	0
Fuel Cell Air Cooler	11.34	11.34	0	7.87	7.87	0
Water Tank ( Empty)	18.14	18.14	0	37.86	37.86	0
Compressor/Expander	6.0	3.0	50.0	8.0	4.0	50.0
Thermal Insulation	4.54	4.54	0	35.40	35.40	0
Spool Valve	1.42	1.42	0	1.77	1.77	0
Instrumentation/Controls	11.34	11.34	0	8.50	8.50	0
Totals	862.75	175.28	79.7	906.46	178.63	80.3

MTI and CAT believe the size and weight reductions presented in Table 1 are achievable. A 25% reduction in size will be realized by pressurizing the system to three atmospheres. Full integration of the current breadboard design will result in an additional 25-30% reduction in size and weight. Finally, an additional 10-15% reduction can be realized through improved catalyst performance. Small reductions in size and weight of the other components are anticipated, but not included in the estimates. For example, the reduction indicated for the compressor/expander are based on DOE goals for automotive fuel cell turbomachinery.

Rapid response is typically associated with partial oxidation reformers because the heat is released directly in the reformer bed. However, if measures are not taken to simultaneously heat the water-gas-shift and CO cleanup components total start-up time will be limited by the heat up rate of these components. The MTI/CAT fuel processor addresses this issue with an innovative heat integration arrangement. Start-up time is reduced by simultaneously firing the start-up burner and initiating fuel combustion within the reformer. The liquid fuel is mechanically vaporized and ignited by spark ignition in both places. The exhaust gases from the burner are also routed through the expander to recover pressure energy as electrical energy. The spool valve makes the smooth transition possible.

During start-up, the system uses on-board battery power to operate the compressor/expander, drive the wheels, operate the fuel and water pumps, and provide spark ignition to initiate fuel processing. The other components do not require electrical power to operate. Initially, only fuel and air are introduced to the fuel processor. The fuel is mechanically atomized to fine droplets and ignited with a spark ignitor upstream of the reformer catalyst bed. In addition, a portion of the fuel is combusted in excess air in the shroud surrounding the reformer and shift reactors. The fuel cell stacks are bypassed during start-up. Once the reformer reactor is up to temperature, the fuel, air and water flows are adjusted until full power is achieved. Airflow (compressor speed) tracks fuel flow following the desired equivalence setpoint curve. A steam/carbon ratio set point

curve is used to set water flow relative to fuel flow. After the hydrogen reaches acceptable purity, it is introduced to the fuel cell stacks. As hydrogen production increases, electrical demand is shifted from the batteries to the fuel cell stack. The system operates at full power using excess power to recharge the battery. Once the battery is fully charged, fuel cell load demand sets fuel flow demand. MTI experience indicates that start-up will take approximately two minutes, but that with the incorporation of developments identified here the startup time can be reduced by approximately 50%.

As a manufacturing team, MTI and CAT are focusing on both technical development aspects of the compact, gasoline fuel processor as well as cost related issues that will ultimately dictate market penetration and acceptance rates. Early attention to issues such as processor design, serviceability, materials, catalysts, and manufacturability will all lead to more favorable economics upon completion of the program and during commercialization. Early technical performance estimates and cost estimates are closely matched to those delineated in the PNGV targets. MTI and CAT are working to a 2004 commercialization date for the technology. We are targeting 2002 to have a prototype version of the fuel processor.

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## **REFERENCES**

1. R.M. Privette, "Compact Fuel Processors for Fuel Cell Systems", Proceedings from the Joint DOE/EPRI/GRI Workshop on Fuel Cell Technology, May 18, 1998.
2. R.M. Privette, "Fuel Processor for Fuel Cell Mobile Electric Power", Proceedings from the DOD Mobile Electric Power Fuel Cell Symposium, April 24, 1997.
3. R.M. Privette, M.A. Perna, K. Kneidel, J. Hartvigsen, S. Elangovan, A. Khandkar, "Status of SOFCo SOFC Technology Development", 1996 Fuel Cell Seminar, Orlando, FL, November 17-20, 1996.
4. R.M. Privette, T.J. Flynn, M.A. Perna, K.E. Kneidel, D.L. King, "Fuel Processing for Military and Commercial Fuel Cell Applications," 1998 Fuel Cell Seminar, Palm Springs, CA, November 16-19, 1998.
5. U.S. Refiners Propose Gasoline Sulfur Cuts, *Oil and Gas Journal*, March 30, 1998, pg. 29.
6. E.A. Barringer, R.M. Privette, "Fuel Cell Training Seminar", Naval Surface Warfare Center, Philadelphia, PA, June 17-18, 1997.