

MULTIFUEL REFORMER R&D*

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ABSTRACT

The on-board fuel for fuel cell powered vehicles may be one or more of hydrogen, methanol, ethanol, natural gas, propane, or other liquified petroleum gases. To use hydrogen as the fuel, suitable means of storing, and subsequently delivering, adequate quantities of the gas must be developed. For all other fuels suitable reformers must be developed to convert the fuel to hydrogen or a hydrogen-rich gas mixture at rates corresponding to the varying power demand rates of the automotive system; this is especially true for the lower temperature fuel cells, such as the polymer electrolyte fuel cell which operates at 80°C and the phosphoric acid fuel cell which operates at 190°C. This paper discusses the key design and performance characteristics of such hydrogen storage and fuel reformer systems for use in stand-alone fuel cell automotive applications.

Hydrogen Storage

- (1) The primary requirement is the ability to store the amount of hydrogen needed to provide the desired operating range for the vehicle. For example, a 4-passenger car with a range of 300 km at cruising speeds would require a recoverable hydrogen storage capacity of about 5 kg.
- (2) There should be no loss of hydrogen from the storage system during the times that the fuel cell power system is turned off. The time needed to refill the system should be of the order of ten minutes or less. The refill procedure must be safe and be simple enough to not require any special skills. Any losses of hydrogen during such transfers must be negligible.

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(3) The system must deliver hydrogen at the required (fluctuating) rates, independent of the amount of hydrogen remaining in the storage system.

Fuel Reformer

(1) The reformer must start up rapidly and be able to deliver hydrogen to the fuel cell within the time it takes for the fuel cell to begin delivering power.

(2) The reformer must have good dynamic response, i.e., be able to process fluctuating fuel flow rates without significant degradation of reformate quality.

(3) The reformer must provide high fuel conversion with high conversion efficiency at all loads.

Both the hydrogen storage and reformer systems should not add unduly to the size or weight of the propulsion system, should be simple in design and construction to permit easy maintenance, and be fully integrated with the fuel cell stack and the balance of the plant. This integration, however, must not be at the expense of good dynamic performance.

The Department of Energy is initiating a project for the evaluation of hydrogen storage and fuel reforming concepts and the building of prototype systems for use in transportation applications. While this project will be carried out by a commercial organization, our analysis of the considerations for fuel reforming lead to the following conclusions for reformers:

- The fuel reformer should incorporate a small catalyst bed for rapid start-up and low volume and weight. It should use multiple catalysts for optimum operation of the fuel dissociation, reforming, and shift reactions.
- The fuel reformer should use direct heat transfer partial oxidation reforming for rapid response to fluctuating fuel flow rates.
- To provide rapid response to load changes, the fuel reformer should be thermally independent from the rest of the fuel cell system, although thermal integration with the fuel cell stack is desirable for periods of steady loads on the system, such as for long distance travel at more or less constant speeds.

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**Automotive Technology Development-
Contractors' Coordination Meeting
Dearborn, MI**

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Objective

To identify the key design and performance characteristics of hydrogen storage and fuel reformer systems for use with stand alone fuel cell automotive propulsion systems

For Automotive Fuel Cell Applications, A Hydrogen Storage System Must...

- ◆ Be able to store 5 kg of hydrogen, for a 4-passenger car with a range of 300 km
- ◆ Not lose any hydrogen when fuel cell is not in use; losses during transfers must be negligible; and the refilling process must be safe, rapid, and simple
- ◆ Deliver hydrogen at the varying demand rates, independent of its hydrogen content

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For Automotive Fuel Cell Applications, A Fuel Reformer Must...

- ◆ Start-up in a matter of seconds, or deliver H₂ at least as quickly as the fuel cell is ready to deliver power
- ◆ Respond rapidly to changing fuel demand rates
- ◆ Maintain product gas quality, i.e., low CO, high H₂, and high fuel conversion over the entire load range

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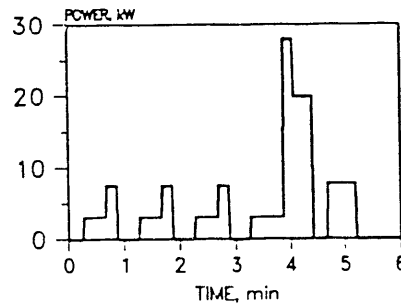
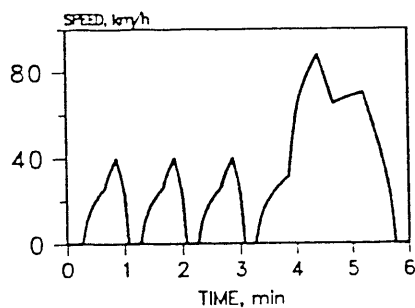
DOE Initiative

The Department of Energy is initiating a project to evaluate hydrogen storage and fuel reforming concepts for application to fuel cell power systems in transportation. Prototype hardware based on the most promising approaches will be built by a commercial organization

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Automotive Power Systems Must Meet Widely Fluctuating Demands

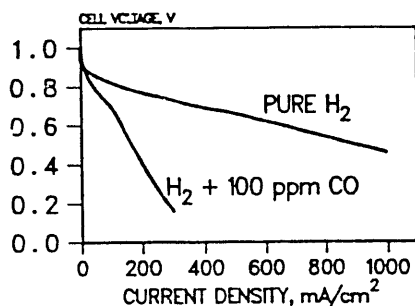
Speed and power profiles for the IETV-1 driven on the Simplified Federal Urban Driving Schedule:



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Fuel Cell Performance is Affected by Reformate Quality

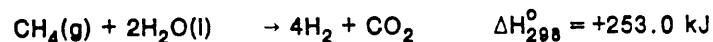
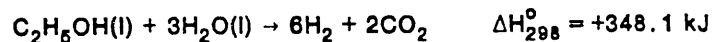
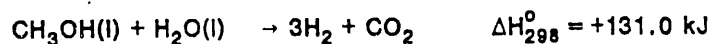
Trace levels of CO significantly decrease cell performance
(LANL Data for the PEFC)



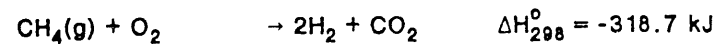
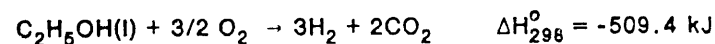
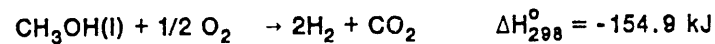
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Thermodynamics of Multifuel Reforming

Steam reforming (needs input of heat):

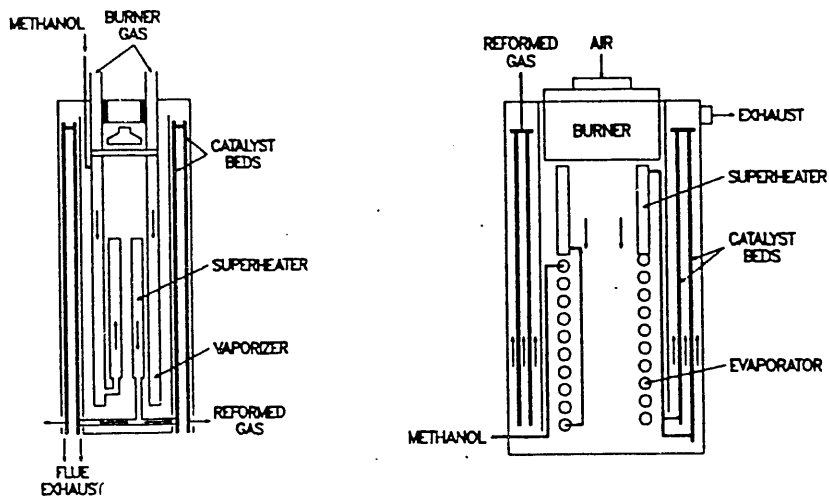


Partial oxidation reforming (needs no external heat):



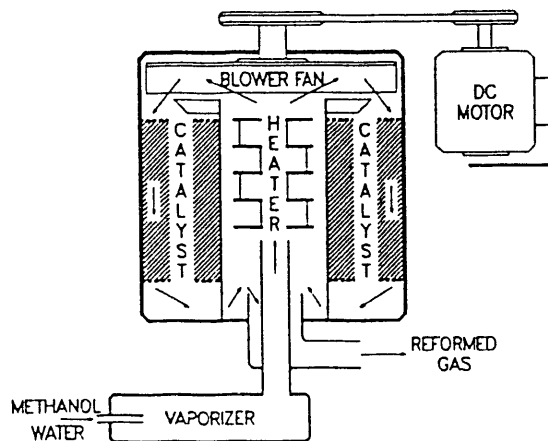
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Examples of Steam Reformers For Constant Load Applications



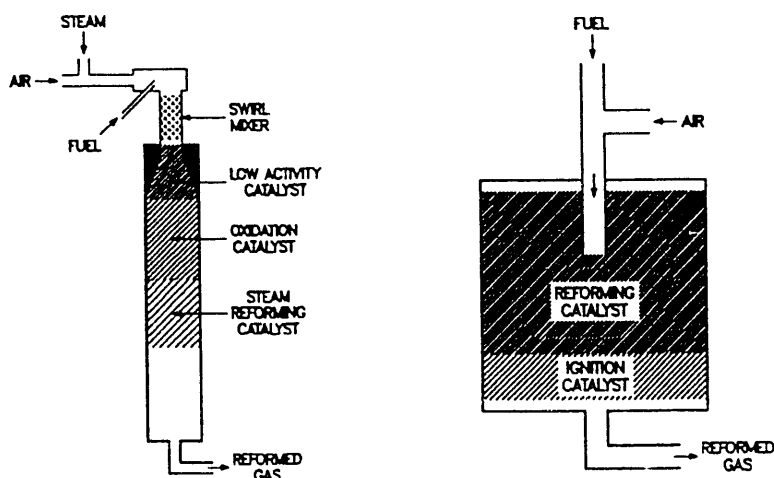
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LANL's Recirculating Steam Reformer Design Offers Rapid Response to Fluctuating Loads



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Partial Oxidation Reformers Can Be Compact and Simple In Design and Fabrication



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Methanol: Steam Reforming *vs* Partial Oxidation Partial Oxidation Offers Some Practical Advantages

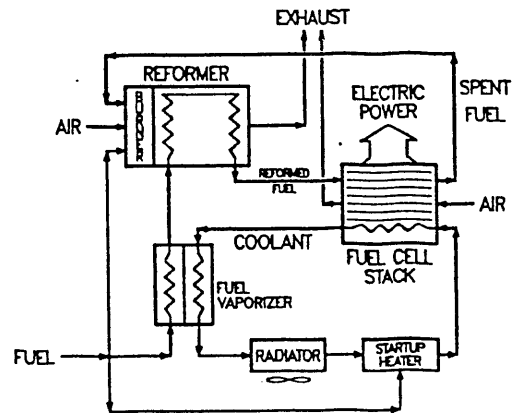
	<u>Steam Reforming</u>	<u>Partial Oxidation</u>
◆ Gas Composition (vol %)		
H ₂	63	48
CO ₂	22	20
H ₂ O	11	11
N ₂	4	21
◆ System Efficiency, %	44 (32)	32
◆ Transient Response	limited (indirect heat transfer)	good (direct heat transfer)
◆ Other Factors		
Size	large	small
Weight	heavy	light
Design	complex	simple

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Reformer/Fuel Cell Integration Issues

Use of stack waste heat and spent fuel combustion:

- ◆ Improves system efficiency
- ◆ Degrades dynamic performance



Reformer/Fuel Cell Integration Issues System Efficiency

- ◆ Use of stack waste heat and of the energy in the spent fuel gas for vaporizing/reforming fuel improves system efficiency
- ◆ In a low temperature fuel cell system, e.g., PEM, the stack waste heat is available at too low a temperature to vaporize water or pressurized methanol
- ◆ In a higher temperature fuel cell system, e.g., PAFC, the stack waste heat can be used for the vaporization of water and methanol
- ◆ In any fuel cell system, heat of combustion of the spent fuel gas can be used to vaporize and/or reform the fuel mixture

Reformer/Fuel Cell Integration Issues System Dynamics

- ◆ A step change in electric power demand requires a corresponding change in the fuel input rate to the fuel cell stack
- ◆ Energy is needed for fuel processing *before* the fuel cell stack produces the corresponding waste heat or spent fuel
- ◆ A thermally decoupled reformer/fuel cell system can have a much better dynamic performance than an integrated reformer/fuel cell system

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In Conclusion: A Fuel Reformer Suitable for Automotive Applications Should Have...

- ◆ Multiple catalysts for optimum operation of the dissociation, oxidation, and shift reactions
- ◆ A minimum amount of catalysts for quick starting, low weight, and small overall size
- ◆ Thermal independence from the fuel cell stack for improved dynamic response
- ◆ Direct heat transfer (i.e., partial oxidation) for rapid start-up, fast response to load variations, and small size

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