

***FCTAP***

***Fuel Cell Technical Advisory Panel***

**STATUS AND PROSPECTS OF FUEL CELLS  
AS AUTOMOBILE ENGINES**

**A REPORT OF THE  
FUEL CELL TECHNICAL ADVISORY PANEL**

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## EXECUTIVE SUMMARY

This report presents the results of a study to (1) determine the technical status of fuel cells being developed for automobile propulsion, (2) assess the capabilities, commitments and plans of the leading organizations in the field, and (3) judge the prospects of fuel cell electric engines (and thus, vehicles) to become commercially available within the next 5-10 years. The study was performed by the Fuel Cell Technical Advisory Panel to assist the State of California Air Resources Board in developing an independent judgment of emerging automotive fuel cell technology and its potential for becoming a competitive engine option for near-zero-emission, high-efficiency automobiles.

The Panel acquired information from responses to a widely distributed questionnaire and in visits with organizations considered leaders in key aspects of fuel cell electric engine and vehicle development. The investigation focused on proton exchange membrane (PEM) fuel cell technology and systems in the belief that the PEM technology offers better prospects than other types of fuel cells to meet automotive engine performance, durability and cost criteria. Information was solicited on the factors that determine fuel cell engine prospects most directly: current and projected performance of PEM fuel cell stacks, fuel processors and integrated engine systems; the most critical component and subsystem cost targets and the prospects for achieving them; fuel choices and their technical and infrastructure implications; and the capabilities and commitments of leading organizations engaged in, or associated with the comprehensive programs now in place to develop, engineer and manufacture complete fuel cell electric engines and to integrate them into mass produced vehicles.

From its critical discussion and review of the information collected, the Panel concludes that the impressive advances in hydrogen-air PEM fuel cell stack technology in recent years have overcome the technical barriers to attaining the high stack performance needed for fuel cell electric vehicle engines. Hydrogen, however, is not considered a technically and economically feasible fuel for private automobiles now nor in the foreseeable future. Automotive fuel cell engines must be able to use widely available, inexpensive liquid fuels such as gasoline or similar petroleum distillate fuels, or methanol if it can be supplied at competitive cost in the amounts needed. PEM fuel cells have shown some ability to use methanol directly, but breakthroughs in electrode performance and membrane resistance to methanol diffusion are needed before the direct methanol fuel cell can be

considered a candidate for development of fuel cells for automobiles. Practical fuel cell electric engines for automobiles, therefore, must have fuel processors capable of converting gasoline or methanol into a hydrogen-rich fuel gas that can be used by the PEM stacks to generate power.

Methanol has been selected by the European and Japanese automotive fuel cell development programs because it is considered easier to process and expected to result in somewhat higher fuel efficiency as well as lower overall carbon dioxide production. The methanol industry appears confident that the required expansions of the methanol supply (from conversion of natural gas) and distribution infrastructures can be put in place at the rate and costs required by an expanding population of fuel cell electric vehicles. In the United States, gasoline is being stressed increasingly for automotive fuel cells because of the existing fuel infrastructure. It is not clear, however, whether today's pump gasoline will be compatible with PEM fuel cell systems for long periods, and the best petroleum-derived fuel for automotive fuel cells may well be a simple distillate cut (without additives) from which sulfur has been largely removed at the refinery.

Because all fuel processor types comprise multiple process units and involve extensive thermal integration within the processor and with other parts of the fuel cell system, they pose difficult development problems. Several leading programs have succeeded in developing processors to the proof-of-principle ("breadboard") stage but none of these meets all the criteria for automotive applications; rapid cold start is a particularly difficult, as yet unmet requirement.

Stacks, fuel processors and other essential balance-of-plant components need to be integrated into complete fuel cell engines that have acceptable weight, volume and operating characteristics while realizing the near-zero-emissions and high-efficiency potential of fuel cells. This integration, the central technical challenge in fuel cell engine system development, has been attained in a few development programs, but only on the breadboard level. Daimler-Benz has taken the key step of integrating a methanol fuel processor with a PEM stack and the necessary balance of plant equipment into an experimental fuel cell electric vehicle. While driveability has been established and the first measurements tend to confirm the expectation of extremely low emissions, this "NeCar 3" vehicle is a rolling test bed rather than a prototype.

The other key challenge in automotive fuel cell development — achievement of manufactured costs comparable to the very low costs of internal combustion engines — translates into stringent cost goals for every material, component, manufacturing step and assembly operation used to produce future fuel cell engines. Consideration of the materials and component costs suggests that there are no fundamental barriers to achieving PEM stack cost goals. The cost prospects of fuel processors and other key subsystems are less well understood at present, but it is clear that mass production on the level of at least 100,000 engines per year will be essential for all

parts of the fuel cell engine system. The leading programs are becoming increasingly involved in developing the mass manufacturing methods that will be required to achieve cost goals.

Major efforts are now underway in North America, Europe and Japan to develop all aspects of automotive PEM fuel cell technology. They are being undertaken by the organizations whose participation and leadership is essential if a commercially viable fuel cell electric engine is to emerge: leading automobile manufacturers with track records in advanced automotive technology, including the development of electric and hybrid vehicles. Equally important, the world's leaders in PEM fuel cell technology are, or will soon be, participating in key alliances with these manufacturers. The integrated efforts are supported by well-focused government R&D programs of significant size (especially in the United States), and they draw on the advanced technology leadership of a growing number of organizations who look to PEM automotive fuel cells as a potentially large business opportunity for their specialized products and skills.

In the Panel's estimate, the R&D investments made to date and the commitments for the next few years by major fuel cell developers and automobile manufacturers already are between \$1.5 and 2 billion, and additional resources — both, financial resources and technical capabilities — are likely to be committed as programs move increasingly from R&D into the more expensive phases of engine systems integration and evaluation/testing, engineering of all component, subsystem and system technologies for low cost mass production, and development of the required manufacturing processes.

As discussed in some detail in this report, past efforts have resulted in remarkable advances in almost every aspect of automotive fuel cell technology, but major steps are still ahead even for the most advanced programs. At this time, the most compelling argument for the Panel's cautious optimism about the prospects for ultimate success is that the promise of fuel cells as an environmentally superior and more efficient automobile engine is being pursued with an unprecedented combination of resources by powerful organizations acting in their own interest and with strong public support. The Panel, therefore, considers the statements of several major automobile manufacturers — that they expect to have production-ready fuel cell electric vehicles by

Given the current status, the steps still ahead, and the limited time available for their completion, success at every turn and manufacturing investment decisions at the earliest possible times will be required to commercialize fuel cell electric engines and vehicles in a short 6 years from now.

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The final presentation of the Panel's findings and conclusions is, of course, the responsibility of the authors.

## **IN MEMORIAM**

This report is dedicated to the memory of Dr. Carl B. Moyer, Chief Scientist of the Acurex Corporation (now Arcadis) and Co-Chairman of the State of California Battery Technical Advisory Panel, which issued its report to ARB in December 1995. Carl Moyer died on November 29, 1997 — much too soon — and before we were able to draw on his counsel for the Fuel Cell Panel's report. Carl's integrity in receiving and reporting information, his remarkable ability to integrate insights from a wide range of technical subjects and policy debates, and most of all his vision and enthusiasm for a better environment provided inspiration for this report.

Fritz R. Kalhammer, Chairman, FCTAP