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April 4, 2003

Steve Chalk, Director
Office of Hydrogen, Fuel Cells, and Infrastructure Technologies
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Chalk:

In response to a requirement in its statement of task item 5,[1] the National Research Council's (NRC's) Committee on Alternatives and Strategies for Future Hydrogen Production and Use submits this interim letter report.[2] This letter report is part of a larger project initiated at the request of the U.S. Department of Energy (DOE) by the NRC's Board on Energy and Environmental Systems and the National Academy of Engineering Program Office. The purpose of the project is to evaluate the cost and status of technologies for production, transportation, storage, and end-use of hydrogen and to review DOE's hydrogen research, development, and deployment (RD&D) strategy. The committee's observations and findings in this report are based on presentations made by various DOE representatives and others at the committee's first two meetings on December 2-4, 2002, and January 22-24, 2003, in Washington, D.C. This letter report provides some early feedback and recommendations that may be of help as you and your colleagues evolve your strategic directions for the fiscal year 2005 hydrogen research and development (R&D) programs.

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[1] Item 5 of the statement of task asks for a letter report on the committee's interim findings. The balance of the statement of task (see Appendix B) will be addressed in the committee's final report in late 2003.

[2] This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Daniel Arvizu, CH2M Hill; Alan Bard, NAS, University of Texas, Austin; H.M. Hubbard, Retired President and CEO, Pacific International Center for High Technology Research; James Katzer, NAE, ExxonMobil Research and Engineering Company; and Robert Shaw, Jr., Aretê Corporation.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by William Agnew, NAE, General Motors (retired). Appointed by the NRC, he was responsible for making sure that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

INTRODUCTION

Hydrogen is a flexible energy carrier that can be produced from a variety of domestic energy resources and used in all sectors of the economy. An energy system based on domestic energy resources, using hydrogen as a carrier and deployed on a large scale, if accomplished, could improve energy security, air quality, and greenhouse gas management. Such a system will require development across a spectrum of complementary technologies for hydrogen production, transportation, storage, and use.

Today, hydrogen is generated for use in a variety of applications, the most significant of which are the refining of crude oil into commercial liquid fuels and the production of fertilizers and high-value chemicals. Accordingly, a great deal of practical commercial experience exists for producing, transporting, and using hydrogen.

The DOE's Office of Energy Efficiency and Renewable Energy has created a new program office, the Office of Hydrogen, Fuel Cells, and Infrastructure Technologies. The committee applauds DOE for providing one office as the focus for the hydrogen-related programs conducted under different DOE organizations. The purpose of this office is to facilitate overall strategic program direction, coordinate individual hydrogen-related activities across various DOE organizations, promote outreach to the public and private sectors, and coordinate with stakeholder partners.[3] An example of a coordination activity is the National Hydrogen Energy Roadmap (November 2002) [1].

The committee offers four recommendations based on its information gathering and deliberations thus far. Reflecting serious needs in DOE's program identified in an initial assessment by the committee, these recommendations may be refined and expanded upon in the committee's final report. They address a systems approach to hydrogen energy RD&D, exploratory research as the foundation for breakthroughs in technology, safety issues, and coordination of R&D strategy and programs.

SYSTEMS ANALYSIS

In its program overview, DOE personnel presented various R&D targets for a variety of possible future hydrogen energy system components. From its collective experience, the committee deems it essential that the DOE treat hydrogen energy development as a system ranging from hydrogen creation and production to transportation, storage, and end use. It is important that all aspects of the various conceivable hydrogen system pathways be adequately modeled to understand the complex interactions between components, system costs, environmental impacts of individual components and the system as a whole, societal impacts (e.g., offsets of imported oil per year), and possible system trade-offs. Indeed, such an analysis function is an essential tool for DOE personnel to optimally prioritize areas for R&D as well as to understand the ramifications of future R&D successes and disappointments. A competent, independent systems

[3] Chalk, S. Overview of DOE Hydrogen Technology Activities. Presentation to the committee on December 2, 2002.

analysis group not only will help DOE program managers make better program decisions in the future, but also will help:

- Establish a high standard for assessments performed by program contractors,
- Provide a greater degree of confidence in program integrity,
- Enhance the private sector's willingness to participate in the hydrogen program, and
- Minimize the occurrence of unwarranted claims within DOE.

Indeed, in its recent review of the DOE Vision 21 Program [2], the NRC urged the establishment of such a systems analysis function for the coal-based energy program.

Recommendation 1: An independent systems engineering and analysis group should be established within the hydrogen program to identify the impacts of various technology pathways, to assess associated cost elements and drivers, to identify key cost and technological gaps, and to assist in the prioritization of R&D directions. The committee understands that DOE recognizes the importance of systems integration and suggests that its current analytical capabilities could be expanded into an in-house systems analysis group.

EXPLORATORY RESEARCH

A hydrogen economy[4] will not come about without significant improvements in technology. This in turn requires that DOE provide significant funding for fundamental, exploratory research supported by organizations and investigators that propose credible, promising, high-risk new concepts for technologies for hydrogen storage, production, transportation, and end-use. The cost reductions (e.g., fuel cell cost per kilowatt) and infrastructure necessary to bring about a hydrogen economy are indeed challenging. While progress will certainly result from further development and demonstrations of existing technologies, some hydrogen system components will require major scientific breakthroughs that development will not address. Such advances will require entirely new approaches and thinking, which can come about only through relatively fundamental, directed exploratory research aimed at identifying technologies that will achieve cost reduction and technology goals (e.g., weight percentage of stored hydrogen).

Demonstrations also have a place in a balanced research program because they can lead to cost reductions and accelerate the development of codes, standards, environmental permitting, and strategies for inspection and monitoring. But demonstrations can also distort budgets and divert effort toward technology with limited potential. Development of a careful plan for funding and evaluating demonstrations will serve the public interest.

[4] The hydrogen economy has been envisioned as the large-scale use of hydrogen as an energy carrier, generated from any of a variety of fuels or feedstocks, to be used in the transportation, industrial, and building sectors, and requiring an infrastructure for its transmission and delivery.

Recommendation 2: Fundamental and exploratory research should receive additional budgetary emphasis, and the DOE should develop a careful plan for evaluating, funding, and validating emerging technologies for hydrogen production, transportation, storage, and end-use.

SAFETY

The nation's current hydrogen production, transportation, and utilization system is very safely managed [3]. The introduction of hydrogen into the commercial supply and consumption sectors of the economy, however, will present a number of new safety issues, due to hydrogen's wide explosive range and extremely low ignition energy. In addition, safety considerations can affect the choice of technology pathway. Accordingly, safety considerations must be an integral part of DOE's hydrogen program.

Recommendation 3: The committee recommends that DOE make a significant effort to address safety issues, and it supports DOE's plans to incorporate safety considerations into its various hydrogen research, development, and deployment programs.

ORGANIZATION

A transition from the current U.S. energy system to one based on hydrogen will be extremely difficult and challenging and will require a national coordinated effort across DOE's programs and the private sector. The private sector players in that new system will likely include a number of existing industries along with some entirely new companies. Considerable benefit can be gained from the experience and potential contributions of existing industry as well as new companies that may come into being along the way.

Recommendation 4: The committee strongly supports the DOE in its efforts to integrate its various hydrogen-related RD&D programs across the applied energy programs, the Office of Science, and appropriate private sector participants in the planning and development of hydrogen technologies and systems, and it recommends that DOE continue to leverage the knowledge and capabilities of the private sector. The committee further recommends that the Office of Science be integrated better into hydrogen program planning to help facilitate the needed exploratory research mentioned in Recommendation 2.

Michael P. Ramage, *Chair*
Committee on Alternatives and Strategies for Future Hydrogen Production and Use

References:

[1] U.S. Department of Energy. National Hydrogen Energy Roadmap. November 2002.
[2] National Research Council. Review of DOE's Vision 21 Research and Development Program: Phase 1. National Academies Press, Washington, D.C. 2003.

[3] Thomas, C.E. Direct-Hydrogen-Fueled Proton-Exchange Membrane Fuel Cell System for Transportation Applications: Hydrogen Vehicle Safety Report, DOE/CE/5039-502. U.S. Department of Energy, Washington, D.C. 1997.

Appendix A

Committee Members and Staff

Committee on Alternatives and Strategies for Future Hydrogen Production and Use

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[1]NAE, National Academy of Engineering.

Appendix B

Statement of Task

This study is similar in intent to a 1990 report by the National Research Council (NRC), *Fuels to Drive Our Future*, which evaluated the options for producing liquid fuels for transportation use. The use of that comprehensive study was proposed by DOE as the model for this one on hydrogen. With revisions to account for the different end-use applications, process technologies, and current concerns about climate change and energy security, it will be used as a general guide for the report to be produced in this work. In particular, the NRC will appoint a committee that will address the following tasks:

1. Identify and evaluate the current status of the major alternative technologies and sources for producing hydrogen, for transmitting and storing hydrogen, and for using hydrogen to provide energy services especially in the transportation, but also the utility, residential, industrial and commercial sectors of the economy.
2. Assess the feasibility of operating each of these conversion technologies both at a small scale appropriate for a building or vehicle and at a large scale typical of current centralized energy conversion systems such as refineries or power plants. This question is important because it is not currently known whether it will be better to produce hydrogen at a central facility for distribution or to produce it locally near the points of end-use. This assessment will include factors such as societal acceptability (the NIMBY problem), operating difficulties, environmental issues including CO_2 emission, security concerns, and the possible advantages of each technology in special markets such as remote locations or particularly hot or cold climates.
3. Estimate current costs of the identified technologies and the cost reductions that the committee judges would be required to make the technologies competitive in the market place. As part of this assessment, the committee will consider the future prospects for hydrogen production and end-use technologies (e.g., in the 2010 to 2020, 2020 to 2050, and beyond 2050 time frames). This assessment may include scenarios for the introduction and subsequent commercial development of a hydrogen economy based on the use of predominantly domestic resources (e.g., natural gas, coal, biomass, renewables [e.g., solar, geothermal, wind], nuclear, municipal and industrial wastes, petroleum coke, and other potential resources), and consider constraints to their use.
4. Based on the technical and cost assessments, and considering potential problems with making the "chicken and egg" transition to a widespread hydrogen economy using each technology, review DOE's current RD&D programs and plans, and suggest an RD&D strategy with recommendations to DOE on the R&D priority needs within each technology area and on the priority for work in each area.
5. Provide a letter report on the committee's interim findings no later than February 2003 so this information can be used in DOE's budget and program planning for Fiscal Year 2005.
6. Publish a written final report on its work, approximately 13 months from contract initiation.

The committee's interim letter report and final report will be reviewed in accordance with National Research Council (NRC) report review procedures before release to the sponsor and the public.