S. Hrg. 100-501

FUEL CELL RESEARCH AND DEVELOPMENT, AND UTILIZATION POLICY, AND HYDROGEN RESEARCH AND DEVELOPMENT

HEARING

BEFORE THE

SUBCOMMITTEE ON
ENERGY RESEARCH AND DEVELOPMENT

OF THE

COMMITTEE ON
ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

FIRST SESSION

ON

S. 1294

TO PROMOTE THE DEVELOPMENT OF TECHNOLOGIES WHICH WILL ENABLE FUEL CELLS TO USE ALTERNATIVE FUEL SOURCES

S. 1295

TO DEVELOP A NATIONAL POLICY FOR THE UTILIZATION OF FUEL CELL TECHNOLOGY

S. 1296

TO ESTABLISH A HYDROGEN RESEARCH AND DEVELOPMENT PROGRAM

SEPTEMBER 23, 1987

88-211-P

Printed for the use of the
Committee on Energy and Natural Resources

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FUEL CELL RESEARCH AND DEVELOPMENT, AND UTILIZATION POLICY, AND HYDROGEN RESEARCH AND DEVELOPMENT

TUESDAY, SEPTEMBER 23, 1987

U.S. Senate,
Subcommittee on Energy Research and Development,
Committee on Energy and Natural Resources,
Washington, DC.

The subcommittee met, pursuant to notice, at 2:04 p.m., in room SD-366, Dirksen Senate Office Building, Hon. Wendell H. Ford, presiding.

OPENING STATEMENT OF HON. WENDELL H. FORD, A U.S. SENATOR FROM THE STATE OF KENTUCKY

Senator Ford. The committee will come to order.

I am pleased to be here today to chair the hearing on S. 1294, to promote the development of technologies which will enable fuel cells to use alternative fuel sources; S. 1295, to develop a national policy for the utilization of fuel cell technology; and S. 1296, to establish the hydrogen research and development program.

This country has been concerned about our dependence on foreign sources of energy since the early 1970s. We wanted to insulate ourselves from the disastrous effects of all supply disruptions. So, we began researching all sorts of alternative energy sources, including fuel cells and hydrogen. We were looking and we are still looking for better and cheaper ways of using our own resources, instead of to imported oil.

The price of oil has declined since then tremendously, and unfortunately so has the interest and the funding for research into alternative energy sources. These bills are important and timely in that they reaffirm our commitment of development of alternative energy resources.

Fuel cells, which are like batteries with a continuous source of energy, can be run with renewable resources. Fuel cells are highly energy efficient and modular. There is a short lead time for construction of fuel cells, and they don't pollute the environment.

Hydrogen is produced from the earth's most abundant resource, water. Scientists say that hydrogen has the potential to be an increasingly important source of energy for the future.

There was an interesting article on this subject in the Outlook section of the Washington Post a few weeks back. The newspaper said that the Outlook section "examines contemporary ideas that are changing our lives and expanding our intellectual frontiers.

Many of the prominent researchers that are interviewed in this article will appear today as witnesses. We look forward to having them expand our intellectual frontiers through their testimony.

I would like to thank my distinguished colleague from Hawaii, Senator Sparky Matsunaga, for his leadership in promoting alternative energy resources. And Sparky, we are looking forward to hearing your testimony today. And if you wish, I invite you to join the subcommittee for the remainder, if you wish to, listen to the testimony and ask any questions from our distinguished visitors. So, the welcome mat is out to you. And we are delighted that you are here and welcome your testimony this afternoon.

[The texts of S. 1294, S. 1295, and S. 1296, a statement from Senator Weicker and the article from the Washington Post follow:]

II

100TH CONGRESS
1ST SESSION

S. 1294

To promote the development of technologies which will enable fuel cells to use alternative fuel sources.

IN THE SENATE OF THE UNITED STATES

MAY 28, 1987

Mr. MATSUNAGA (for himself, Mr. WEICKER, Mr. INOUYE, Mr. MURKOWSKI, Mr. BINGAMAN, and Mr. HECHT) introduced the following bill; which was read twice and referred to the Committee on Energy and Natural Resources

---

A BILL

To promote the development of technologies which will enable fuel cells to use alternative fuel sources.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Renewable Energy/Fuel Cell Systems Integration Act of 1987".

SEC. 2. FINDINGS AND PURPOSE.

(a) FINDINGS.—The Congress finds that while the Federal Government has invested heavily in fuel cell technology over the past 10 years ($334,700,000 in research and development on fuel cells for electric power production), research on technologies that enable fuel cells to use alternative fuel sources needs to be undertaken in order to fulfill the conservation promise of fuel cells as an energy source.

(b) PURPOSE.—The purpose of this Act is to provide funds for research on technologies that will enable fuel cells to use alternative fuel sources.

SEC. 3. RESEARCH PROGRAM.

(a) PROGRAM AUTHORIZATION.—The Secretary of Energy shall implement and carry out a research program for the purpose of—

(1) exploring the operation of fuel cells employing methane gas generated from various forms of biomass;

(2) developing technologies to use renewable energy sources, including wind and solar energy, to produce hydrogen for use in fuel cells; and

(3) determining the technical requirements for employing fuel cells for electric power production as backup spinning reserve components to renewable power systems in rural and isolated areas.

(b) GRANTS.—In carrying out the research program authorized in subsection (a), the Secretary of Energy may make grants to, or enter into contracts with, private research laboratories.

SEC. 4. REPORT TO CONGRESS.

The Secretary of Energy shall transmit to the Congress on or before September 30, 1989, a comprehensive report on research carried out pursuant to this Act.

SEC. 5. AUTHORIZATION.

There are hereby authorized to be appropriated $5,000,000 for fiscal year 1988 to the Secretary of Energy to be used to conduct research as provided in this Act.

II

100TH CONGRESS
1ST SESSION

S. 1295

To develop a national policy for the utilization of fuel cell technology.

IN THE SENATE OF THE UNITED STATES

MAY 28, 1987

Mr. MATSUNAGA (for himself, Mr. WEICKER, Mr. INOUYE, Mr. MURKOWSKI, and Mr. BINGAMAN) introduced the following bill; which was read twice and referred to the Committee on Energy and Natural Resources

---

A BILL

To develop a national policy for the utilization of fuel cell technology.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Fuel Cells Energy Utilization Act of 1987".

SEC. 2. FINDINGS.

The Congress finds that—

(1) while the Federal Government has invested substantially in fuel cell technology through research and development during the past 10 years, there is no

national policy for acting upon the findings of this research and development; and

(2) if such a national policy were developed, the public investment in fuel cell technology would be realized through reduced dependency on imported oil for energy and the consequent improvement in the international trade accounts of the United States.

SEC. 3. INCLUSION OF FUEL CELLS AS A FUEL CONSERVATION TECHNOLOGY UNDER REIDA.

Section 256 of the Energy Policy and Conservation Act is amended by inserting at the end thereof the following:

"(e) For purposes of this section, the term 'domestic renewable energy industry' shall include industries using fuel cell technology.".

SEC. 4. ENVIRONMENTAL PROTECTION AGENCY GUIDELINES FOR USE OF FUEL CELL TECHNOLOGIES.

Within 180 days of the date of enactment of this Act, the Administrator of the Environmental Protection Agency shall prepare Federal guidelines for cities and municipalities specifying environmental and safety standards for the use of fuel cell technology. In the preparation of the guidelines, the Administrator shall utilize the successful experience of the New York City Fire Department in the use of fuel cell technologies.

SEC. 5. DEPARTMENT OF COMMERCE INVESTIGATION OF EXPORT MARKET POTENTIAL FOR INTEGRATED FUEL CELL SYSTEMS.

Within 180 days of the date of enactment of this Act, the Secretary of Commerce shall assess and report to Congress concerning the export market potential for integrated systems of fuel cells with renewable power technologies.

II

100TH CONGRESS
1ST SESSION

S. 1296

To establish a hydrogen research and development program.

IN THE SENATE OF THE UNITED STATES

MAY 28, 1987

Mr. MATSUNAGA (for himself, Mr. EVANS, and Mr. INOUYE) introduced the following bill; which was read twice and referred to the Committee on Energy and Natural Resources

A BILL

To establish a hydrogen research and development program.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Hydrogen Research and Development Act".

TITLE I—HYDROGEN PRODUCTION AND USE

FINDINGS AND PURPOSE

SEC. 101. (a) The Congress finds that—

(1) due to the limited quantities of naturally occurring petroleum-based fuels, viable alternative fuels and feedstocks must be developed;

(2) priority should be given to the development of alternative fuels with universal availability;

(3) hydrogen is one of the most abundant elements in the Universe, with water, a primary source of hydrogen, covering three-fourths of the Earth;

(4) hydrogen appears promising as an alternative to environmentally damaging fossil fuels;

(5) hydrogen can be transported more efficiently and at less cost than electricity over long distances;

(6) renewable energy resources are potential energy sources that can be used to convert hydrogen from its naturally occurring states into high quality fuel, feedstock, and energy storage media; and

(7) it is in the national interest to accelerate efforts to develop a domestic capability to economically produce hydrogen in quantities which will make a significant contribution toward reducing the Nation's dependence on conventional fuels.

(b) The purpose of this title is to—

(1) direct the Secretary of Energy to prepare and implement a comprehensive 5-year plan and program to accelerate research and development activities leading to the realization of a domestic capability to produce, distribute, and use hydrogen economically within the shortest time practicable; and

(2) develop renewable energy resources as primary energy sources to be used in the production of hydrogen.

COMPREHENSIVE MANAGEMENT PLAN

SEC. 102. (a) the Secretary shall prepare a comprehensive 5-year program management plan for research and development activities which shall be conducted over a period of no less than 5 years and shall be consistent with the provisions of sections 103 and 104. In the preparation of such plan, the Secretary shall consult with the Administrator of the National Aeronautics and Space Administration, the Secretary of Transportation, the Hydrogen Technical Advisory Panel established under section 106, and the heads of such other Federal agencies and such public and private organizations as he deems appropriate. Such plan shall be structured to permit the realization of a domestic hydrogen production capability within the shortest time practicable.

(b) The Secretary shall transmit the comprehensive program management plan to the Committee on Science, Space, and Technology of the House of Representatives and the Committee on Energy and Natural Resources of the Senate within 6 months after the date of the enactment of this Act. The plan shall include (but not necessarily be limited to)—

(1) the research and development priorities and goals to be achieved by the program;

(2) the program elements, management structure, and activities, including program responsibilities of individual agencies and individual institutional elements;

(3) the program strategies including technical milestones to be achieved toward specific goals during each fiscal year for all major activities and projects;

(4) the estimated costs of individual program items, including current as well as proposed funding levels for each of the 5 years of the plan for each of the participating agencies;

(5) a description of the methodology of coordination and technology transfer; and

(6) the proposed participation by industry and academia in the planning and implementation of the program.

(c) Concurrently with the submission of the President's annual budget to the Congress for each year after the year in which the comprehensive 5-year plan is initially transmitted under subsection (b), the Secretary shall transmit to the Congress a detailed description of the current comprehensive plan, setting forth appropriate modifications which may be necessary to revise the plan as well as comments on and recommendations for improvements in the comprehensive program management plan made by the Hydrogen Technical Advisory Panel established under section 106.

RESEARCH AND DEVELOPMENT

SEC. 103. (a) The Secretary shall establish, within the Department of Energy, a research and development program, consistent with the comprehensive 5-year program management plan under section 102, to ensure the development of a domestic hydrogen fuel production capability within the shortest time practicable.

(b)(1) The Secretary shall initiate research or accelerate existing research in areas which may contribute to the development of hydrogen production and use.

(2) Areas researched shall include production, liquefaction, transmission, distribution, storage, and use. Particular attention shall be given to developing an understanding and resolution of all potential problems of introducing hydrogen production and use into the marketplace.

(c) The Secretary shall give priority to those production techniques that use renewable energy resources as their primary energy source.

(d) The Secretary shall, for the purpose of performing his responsibilities pursuant to this title, solicit proposals for and evaluate any reasonable new or improved technology, a description of which is submitted to the Secretary in writing, which could lead or contribute to the development of hydrogen production technology.

(e) The Secretary shall conduct evaluations, arrange for tests and demonstrations, and disseminate to developers information, data, and materials necessary to support efforts undertaken pursuant to this section.

DEMONSTRATIONS AND PLAN

SEC. 104. (a)(1) The Secretary shall conduct demonstrations of hydrogen technology, preferably in self-contained locations, so that technical and nontechnical parameters can be evaluated to best determine commercial applicability of the technology.

(2) Concurrently with activities conducted pursuant to section 103, the Secretary shall conduct small-scale demonstrations of hyrdogen technology at self-contained sites.

(b) The Secretary shall, in consultation with the Secretary of Transportation, the Administrator of the National Aeronautics and Space Administration, and the Hydrogen Technical Advisory Panel established under section 106, prepare a comprehensive large-scale hydrogen demonstration plan with respect to demonstrations carried out pursuant to subsection (a)(1). Such plan shall include—

(1) a description of the necessary research and development activities that must be completed before initiation of a large-scale hydrogen production demonstration program;

(2) an assessment of the appropriateness of a large-scale demonstration immediately upon completion

of the necessary research and development activities; and

(3) an implementation schedule with associated budget and program management resource requirements.

COORDINATION AND CONSULTATION

SEC. 105. (a) The Secretary shall have overall management responsibility for carrying out the program under this title. In carrying out such program, the Secretary, consistent with such overall management responsibility—

(1) shall use the expertise of the National Aeronautics and Space Administration and the Department of Transportation; and

(2) may use the expertise of any other Federal agency in accordance with subsection (b) in carrying out any activities under this title, to the extent that the Secretary determines that any such agency has capabilities which would allow such agency to contribute to the purpose of this title.

(b) The Secretary may, in accordance with subsection (a), obtain the assistance of any department, agency, or instrumentality of the Executive branch of the Federal Government upon written request, on a reimbursable basis or otherwise and with the consent of such department, agency, or instrumentality. Each such request shall identify the assistance the Secretary deems necessary to carry out any duty under this title.

(c) The Secretary shall consult with the Administrator of the National Aeronautics and Space Administration, the Administrator of the Environmental Protection Agency, the Secretary of Transportation, and the Hydrogen Technical Advisory Panel established under section 106 in carrying out his authorities pursuant to this title.

TECHNICAL PANEL

SEC. 106. (a) There is hereby established a technical panel of the Energy Research Advisory Board, to be known as the Hydrogen Technical Advisory Panel, to advise the Secretary on the program under this title.

(b)(1) The technical panel shall be appointed by the Secretary and shall be comprised of such representatives from domestic industry, universities, professional societies, Government laboratories, financial, environmental, and other organizations as the Secretary, in consultation with the Chairman of the Energy Research Advisory Board, deems appropriate based on his assessment of the technical and other qualifications of such representatives. Appointments to the technical panel shall be made within 90 days after the enactment of this Act. The technical panel shall have a chairman, who shall be elected by the members from among their number.

(2) Members of the technical panel need not be members of the full Energy Research Advisory Board.

(c) The activities of the technical panel shall be in compliance with any laws and regulations guiding the activities of technical and fact-finding groups reporting to the Energy Research Advisory Board.

(d) The heads of the departments, agencies, and instrumentalities of the Executive branch of the Federal Government shall cooperate with the technical panel in carrying out the requirements of this section and shall furnish to the technical panel such information as the technical panel deems necessary to carry out this section.

(e) The technical panel shall review and make any necessary recommendations on the following items, among others—

(1) the implementation and conduct of the program under this title; and

(2) the economic, technological, and environmental consequences of the deployment of hydrogen production and use systems.

(f) The technical panel shall prepare and submit annually to the Energy Research Advisory Board a written report of its findings and recommendations with regard to the program under this title. The report shall include—

(1) a summary of the technical panel's activities for the preceding year;

(2) an assessment and evaluation of the status of the program; and

(3) comments on and recommendations for improvements in the comprehensive 5-year program management plan required under section 102.

(g) After consideration of the technical panel report and within 30 days after its receipt, the Energy Research Advisory Board shall submit the report, together with any comments which the Board deems appropriate, to the Secretary.

(h) The Secretary shall provide such staff, funds, and other support as may be necessary to enable the technical panel to carry out the functions described in this section.

DEFINITIONS

SEC. 107. As used in this title—

(1) the term "Secretary" means the Secretary of Energy; and

(2) the term "capability" means proven technical ability.

AUTHORIZATION OF APPROPRIATIONS

SEC. 108. There is hereby authorized to be appropriated to carry out the purpose of this title (in addition to any amounts made available for such purpose pursuant to other Acts)—

(1) $10,000,000 for the fiscal year beginning October 1, 1987;

(2) $15,000,000 for the fiscal year beginning October 1, 1988;

(3) $20,000,000 for the fiscal year beginning October 1, 1989;

(4) $25,000,000 for the fiscal year beginning October 1, 1990; and

(5) $30,000,000 for the fiscal year beginning October 1, 1991.

TITLE II—HYDROGEN-FUELED AIRCRAFT RESEARCH AND DEVELOPMENT

FINDINGS AND PURPOSE

SEC. 201. (a) The Congress finds that—

(1) long-term future decreases in petroleum-base fuel availability will seriously impair the operation of the world's air transport fleets;

(2) hydrogen appears to be an attractive alternative to petroleum in the long term to fuel commercial aircraft;

(3) it is therefore in the national interest to accelerate efforts to develop a domestic hydrogen-fueled supersonic and subsonic aircraft capability; and

(4) the use of liquid hydrogen as a commercial air transport fuel has sufficient long-term promise to justify

a substantial research, development, and demonstration program.

(b) The purpose of this title is to—

(1) direct the Administrator of the National Aeronautics and Space Administration to prepare and implement a comprehensive 5-year plan and program for the conduct of research, development, and demonstration activities leading to the realization of a domestic hydrogen-fueled aircraft capability within the shortest time practicable;

(2) establish as a goal broad multinational participation in the program; and

(3) provide a basis for public, industry, and certifying agency acceptance of hydrogen-fueled aircraft as a mode of commercial air transport.

COMPREHENSIVE MANAGEMENT PLAN

SEC. 202. (a) The Administrator shall prepare a comprehensive 5-year program management plan for research, development, and demonstration activities consistent with the provisions of sections 203, 204, and 205. In the preparation of such plan, the Administrator shall consult with the Secretary of Energy, the Secretary of Transportation, and the heads of such other Federal agencies and such public and private organizations as he deems appropriate. Such plan shall be structured to permit the realization of a domestic hydrogen-fueled aircraft capability within the shortest time practicable.

(b) The Administrator shall transmit the comprehensive 5-year program management plan to the Committee on Science, Space, and Technology of the House of Representatives and the Committees on Commerce, Science, and Transportation and Energy and Natural Resources of the Senate within 6 months after the date of the enactment of this Act. The plan shall include (but not necessarily be limited to)—

(1) the research and development priorities and goals to be achieved by the program;

(2) the program elements, management structure, and activities, including program responsibilities of individual agencies and individual institutional elements;

(3) the program strategies including detailed technical milestones to be achieved toward specific goals during each fiscal year for all major activities and projects;

(4) the estimated costs of individual program items, including current as well as proposed funding levels for each of the 5 years of the plan for each of the participating agencies;

(5) a description of the methodology of coordination and technology transfer; and

(6) the proposed participation by industry and academia in the planning and implementation of the program.

(c) Concurrently with the submission of the President's annual budget to the Congress for each year after the year in which the comprehensive 5-year plan is initially transmitted under subsection (b), the Administrator shall transmit to the Congress a detailed description of the current comprehensive plan, setting forth appropriate modifications which may be necessary to revise the plan as well as comments on and recommendations for improvements in the comprehensive program management plan made by the Hydrogen-Fueled Aircraft Advisory Committee established under section 207.

RESEARCH AND DEVELOPMENT

SEC. 203. (a) The Administrator shall establish, within the National Aeronautics and Space Administration, a research and development program consistent with the comprehensive 5-year program management plan under section 202 to ensure the development of a domestic hydrogen-fueled aircraft capability within the shortest time practicable.

(b) The Administrator shall initiate research or accelerate existing research in areas which may contribute to the development of a hydrogen-fueled aircraft capability.

(c) In conducting the program pursuant to this section, the Administrator shall encourage the establishment of domestic industrial capabilities to supply hydrogen-fueled aircraft systems or subsystems to the commercial marketplace.

(d) The Administrator shall, for the purpose of performing his responsibilities pursuant to this Act, solicit proposals for and evaluate any reasonable new or improved technology, a description of which is submitted to the Administrator in writing, which could lead or contribute to the development of hydrogen-fueled aircraft technology.

(e) The Administrator shall conduct evaluations, arrange for tests and demonstrations and disseminate to developers information, data, and materials necessary to support efforts undertaken pursuant to this section.

FLIGHT DEMONSTRATION

SEC. 204. (a) Concurrent with the activities carried out pursuant to section 203, the Administrator shall, in consultation with the Secretary of Transportation, the Secretary of Energy, and the Hydrogen-Fueled Aircraft Advisory Committee established under section 207, prepare a comprehensive flight demonstration plan, the implementation of which shall provide confirmation of the technical feasibility, economic viability, and safety of liquid hydrogen as a fuel for commercial transport aircraft. The comprehensive flight plan shall include—

(1) a description of the necessary research and development activities that must be completed before initiation of a flight demonstration program;

(2) the selection of a domestic site where demonstration activities can lead to early commercialization of the concept;

(3) an assessment of a preliminary flight demonstration to occur concurrently with the later stages of research and development activities; and

(4) an implementation schedule with associated budget and program management resource requirements.

(b) The Administrator shall transmit such comprehensive flight demonstration plan to the Congress within 2 years after the date of the enactment of this Act.

HYDROGEN PRODUCTION AND GROUND FACILITIES

SEC. 205. (a) The Administrator, in consultation with the Secretary of Transportation and the Secretary of Energy, shall define the systems, subsystems, or components associated with the production, transportation, storage, and handling of liquid hydrogen that are specifically required for and unique to the use of such fuel for commercial aircraft application.

(b) The Administrator shall structure the research and development program pursuant to section 203 to allow the development of the systems, subsystems, or components defined pursuant to subsection (a) of this section.

(c) The research and development program for hydrogen production, transportation, and storage systems, subsystems, and components which are suitable for inclusion as part of a fully integrated hydrogen-fueled aircraft system, but which are not being specifically developed for such application shall be the responsibility of the Secretary of Energy. Such activities shall be included as part of the program established pursuant to title I of this Act, and shall be so conducted as to ensure compliance with hydrogen-fueled aircraft system constraints.

COORDINATION AND CONSULTATION

SEC. 206. (a) The Administrator shall have overall management responsibility for carrying out the program under this title. In carrying out such program, the Administrator, consistent with such overall management responsibility—

(1) shall utilize the expertise of the Departments of Transportation and Energy to the extent deemed appropriate by the Administrator, and

(2) may utilize the expertise of any other Federal agency in accordance with subsection (b) in carrying out any activities under this title, to the extent that the Administrator determines that any such agency has capabilities which would allow such agency to contribute to the purposes of this title.

(b) The Administrator may, in accordance with subsection (a), obtain the assistance of any department, agency, or instrumentality of the Executive branch of the Federal Government upon written request, on a reimbursable basis or otherwise and with the consent of such department, agency, or instrumentality. Each such request shall identify the assistance the Administrator deems necessary to carry out any duty under this title.

(c) The Administrator shall consult with the Secretary of Energy, the Administrator of the Environmental Protection Agency, the Secretary of Transportation, and the Hydrogen-Fueled Aircraft Advisory Committee established under section 207 in carrying out his authorities pursuant to this title.

ADVISORY COMMITTEE

SEC. 207. (a) there is hereby established a Hydrogen-Fueled Aircraft Advisory Committee, which shall advise the Administrator on the program under this title.

(b) The Committee shall be appointed by the Administrator and shall be comprised of at least 7 members from industrial, academic, financial, environmental, and legal organizations and such other entities as the Administrator deems appropriate. Appointments to the Committee shall be made within 90 days after the enactment of this Act. The Committee shall have a chairman, who shall be elected by the members from among their number.

(c) the heads of the departments, agencies, and instrumentalities of the Executive branch of the Federal Government shall cooperate with the Committee in carrying out the requirements of this section and shall furnish to the Committee such information as the Committee deems necessary to carry out this section.

(d) The Committee shall meet at least 4 times annually, notwithstanding subsections (e) and (f) of section 10 of Public Law 92–463.

(e) The Committee shall review and make any necessary recommendations on the following items, among others—

(1) the implementation and conduct of the program under this title; and

(2) the economic, technological, and environmental consequences of developing a hydrogen-fueled aircraft capability.

(f) The Committee shall prepare and submit annually to the Administrator a written report of its findings and recommendations with regard to the program under this title. The report shall include—

(1) a summary of the Committee's activities for the preceding year;

(2) an assessment and evaluation of the status of the program; and

(3) comments on and recommendations for improvements in the comprehensive 5-year program management plan required under section 202.

(g) The Administrator shall provide such staff, funds, and other support as may be necessary to enable the Committee to carry out the functions described in this section.

DEFINITIONS

SEC. 208. As used in this title—

(1) the term "Administrator" means the Administrator of the National Aeronautics and Space Administration;

(2) the term "capability" means proven technical ability; and

(3) the term "certifying agency" means any government entity with direct responsibility for assuring public safety in the operation of the air transport system.

AUTHORIZATION OF APPROPRIATIONS

SEC. 209. There is hereby authorized to be appropriated to carry out the purpose of this title—

(1) $10,000,000 for the fiscal year beginning October 1, 1987;

(2) $15,000,000 for the fiscal year beginning October 1, 1988;

(3) $20,000,000 for the fiscal year beginning October 1, 1989;

(4) $25,000,000 for the fiscal year beginning October 1, 1990; and

(5) $30,000,000 for the fiscal year beginning October 1, 1991.

82-464 0 - 88 2

STATEMENT OF SENATOR LOWELL WEICKER, JR.
HEARING BEFORE THE SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT
U.S. SENATE COMMITTEE ENERGY AND NATURAL RESOURCES COMMITTEE
SEPTEMBER 23, 1987

MR. CHAIRMAN, I WOULD LIKE TO THANK YOU FOR HOLDING THIS HEARING TODAY TO CONSIDER THE DEVELOPMENT OF AN IMPORTANT TECHNOLOGY, THE FUEL CELL. AS INTRODUCED WITH MY COLLEAGUE, SENATOR MATSUNAGA, AND OTHERS, THE CONTINUED RESEARCH TO DEVELOP AND COMMERCIALIZE FUEL CELLS REPRESENTS OUR COMMITTMENT TO THE FUTURE OF NEW POWER GENERATION IN THE UNITED STATES. AS WE ALL KNOW, THERE IS A CRITICAL NEED TO DESIGN AND BUILD MORE EFFICIENT AND LESS ENVIRONMENTALLY DAMAGING POWER GENERATION PLANTS THAT CAN UTILIZE A VARIETY OF FUEL SOURCES. I KNOW THAT THIS COMMITTEE CONSIDERS THE POTENTIAL OF ANOTHER ENERGY CRISIS TO BE ONE THE LARGEST THREATS TO OUR NATIONAL SECURITY.

MR. CHAIRMAN, TWO OF THE BILLS BEFORE US TODAY DEAL WITH THE FURTHER DEVELOPMENT OF THE FUEL CELL. THE "RENEWABLE ENERGY/FUEL CELLS SYSTEMS INTEGRATION ACT" SUPPORTS RESEARCH FOR THE PRODUCTION OF HYDROGEN, AND OTHER FUELS, THROUGH THE USE OF RENEWABLE ENERGY AND FROM BIOMASS IN ORDER TO OPERATE FUEL CELLS. THE SECOND BILL, THE "FUEL CELL ENERGY UTILIZATION ACT" WILL CLASSIFY THE USE OF FUEL CELLS AS A DOMESTIC RENEWABLE ENERGY INDUSTRY, REQUIRE THE ENVIRONMENTAL PROTECTION AGENCY TO PREPARE FEDERAL GUIDELINES FOR THE USE OF FUEL CELLS, AND WILL REQUIRE THE DEPARTMENT OF COMMERCE TO ASSESS AND REPORT TO CONGRESS THE EXPORT POTENTIAL FOR FUEL CELLS AND FUEL CELL TECHNOLOGIES. THIS LAST BILL WAS REPORTED FAVORABLY OUT OF THIS COMMITTEE IN THE 99TH CONGRESS.

MR. CHAIRMAN, WITH THIS HEARING IT IS MY HOPE THAT THE FUEL CELL LEGISLATION BEFORE US, ALONG WITH THE HYDROGEN RESEARCH BILL, WILL BE MOVED EXPEDITIOUSLY THROUGH THE COMMITTEE FOR CONSIDERATION BY THE FULL SENATE LATER THIS YEAR. AGAIN MR. CHAIRMAN, THANK YOU FOR HOLDING THIS HEARING TODAY.

The Washington Post
OUTPOSTS

SEP 6 1987

Every week in "Outposts," Outlook examines contemporary ideas that are changing our lives and expanding our intellectual frontiers. This week, Peter Hoffmann examines hydrogen's potential as an energy source. Hoffmann, a correspondent for McGraw-Hill World News and editor of The Hydrogen Letter, is the author of "The Forever Fuel: The Story of Hydrogen."

ENERGY

Fueling the Future with Hydrogen

By Peter Hoffmann B3

HYDROGEN—the simplest and most common element in the universe—may also prove to be the simplest solution to America's long-term energy needs.

Alternative fuels and energy sources have been dormant issues since the days of the oil embargo. But as concern rises over the security of Mideast oil and natural-gas supplies, as well as air pollution, acid rain and the greenhouse effect, those topics are gaining renewed urgency.

As a result, attention is being focused on the promise of methanol (wood alcohol) as an alternative fuel. In recent congressional hearings, American automakers have come out enthusiastically in favor of its development; and the General Services Administration wants to buy 5,000 methanol cars for the government by 1990.

However, methanol or other alcohols derived from coal, grain or biomass, cannot contribute much toward solving the air-pollution problem. It contains only about half as much carbon as the same volume of gasoline or diesel fuel; but it takes about twice as much to do the same job. Thus "the carbon content is the same as gasoline's for the same energy content," says John Appleby, director of Texas A&M's new Center for Electrochemical Systems and Hydrogen Research. So even with widespread use of methanol, carbon-dioxide emissions, a principal contributor to the greenhouse effect, would remain essentially unchanged.

Hydrogen, on the other hand, doesn't pollute at all. Burned in internal-combustion engines, diesels, jets or fuel cells, it produces no carbon monoxides or dioxides, no unburned hydrocarbons, no stench, no smoke, no sulfur-derived compounds to cause acid rain—none of the noxious discharges we suffer today.

And which we pay for unwittingly: In a study published earlier this year, T. Nejat Veziroglu, a researcher at the University of Miami and head of the International Association for Hydrogen Energy, calculated the hidden costs of fossil fuels in terms of human health expenses, deleterious effects on fresh water, farm produce and buildings, and a half dozen other categories. His estimate came to more than $8 per gigajoule of fossil-based energy—approximately the equivalent of 10 gallons of gasoline.

Low Costs and Two Bills

Hydrogen-derived energy, however, has none of those environmental costs. In combustion, its only byproduct is steam. (Plus some nitrogen oxide, unavoidable owing to the fact that air is 80 percent nitrogen—a problem that can be minimized with better combustion technology). And it can be derived from the planet's most ubiquitous resource, water, through the process of electrolysis or other water-splitting methods. [See box.]

That is why Rep. George Brown (D-Calif.) and Sen. Spark Matsunaga (D-Hawaii) are backing hydrogen as the best choice for the post-fossil fuel era. Both have introduced identical bills this session to provide some $200 million in hydrogen-related funding over five years—half devoted to research and development, half to aerospace applications. Subcommittees in the House and Senate have tentatively scheduled hearings on the subject for later this month.

The idea of exploiting hydrogen as a power source is by no means new. As early as 1820 an Oxford don, Rev. William Cecil, regaled fellow academics at Magdalen College with his ideas of a machine powered by hydrogen explosions. And the grandfather of science fiction, Jules Verne, talked about hydrogen power in remarkably prophetic terms in his 1874 novel, "The Invisible Island." Verne foresaw the use of "water as a fuel for steamers and engines" after it was "decomposed into its primitive elements . . . by electricity."

Hydrogen is a chemical energy-carrier, not a primary *source* of energy. That is, it has to be manufactured—through electrolysis or other means—just as electricity has to be generated in power plants. But like electricity, it is easily converted into other forms of energy, and thus can serve as a fungible "currency."

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It was this aspect of hydrogen that appealed to a young Scottish scientist named J.B.S. Haldane. In 1923, he entertained members of a Cambridge University society known as the Heretics with his ideas of an alternative energy system that would store energy generated by wind power as liquid hydrogen. He called hydrogen "weight for weight the most efficient known method of storing energy as it gives about three times as much heat per pound as petrol. On the other hand, it is very light, and bulk for bulk has one one-third the efficiency of petrol. This will not, however, detract from its use in aeroplanes where weight is more important than bulk."

Haldane's prophecy came true in the 1960s when a B-57 jet partially powered on hydrogen flew over Lake Erie. In the '70s, Lockheed conducted studies on liquid-hydrogen-powered subsonic and supersonic jets for NASA and predicted that such planes would be more efficient than their kerosene-powered counterparts. And the National Aerospace Plane project (the hybrid rocket/hypersonic jet endorsed by President Reagan) could *only* operate on liquid hydrogen.

In the first energy trauma of the early 1970s, amid mounting environmental fears, many hydrogen-based research programs were launched. Conferences were held in the United States, Europe and Japan. Jules Verne's script for clean and limitless energy seemed to be around the corner.

Short Memories, Long-Term Gain

Hydrogen seemed the ideal quick-fix miracle fuel, offering an easy way to twist out of OPEC's stranglehold. Already widely used in industry (petroleum refining, chemical manufacture, electronics, glass production and hardening of fats), it could be used to power internal-combustion engines, diesels, jets and fuel cells.

But developing the necessary technology and energy efficiency, even when oil was up to $30-40 a barrel, turned out to be more complex, time-consuming and expensive than anticipated. And as energy prices dropped to near pre-embargo levels in the late 1970s and environmental issues shrank into the background, interest in hydrogen evaporated.

Now interest in alternative energy sources is reviving—especially in import-leery Japan and in Europe, which has been shocked into new alternative-energy awareness by the Chernobyl disaster.

Matsunaga fears that other countries are embarking on hydrogen programs in preparation for the next century that once more may leave the United States in the dust a la steel, microchips, cameras, cars and VCRs: "In this 100th Congress—with its focus on America's standing in the global marketplace—the urgency of establishing a national effort to advance the use of hydrogen energy is more clearly evident than ever," he said in introducing his program. "This is because of the priority given to hydrogen R&D activity by such industrial nations as West Germany and Japan as well as Canada, the Netherlands and Brazil."

The $200-million, five-year plan outlined in the Matsunaga/Brown bills would be a substantial increase over current spending levels, which have averaged $18 million per year: FY 1988 budget requests include about $1 million for administering the Department of Energy; $2.4 million for four hydrogen research institutions in Texas, Hawaii and Florida; and funding for a number of basic research programs throughout DOE.

Getting on Board

By contrast, Canada—which for five years has had a Hydrogen Industry Council (HIC) made up of some 50 companies plus the national and several provincial governments—spent almost $15 million on hydrogen research and development in 1986, most of that from industry, according to Matsunaga.

Germany and Japan have made major commitments. And various companies and government-supported institutions are doing hydrogen-related work in China, Switzerland, Belgium, Holland, Italy and Brazil. France is building a large 2 MW electrolyzer to make hydrogen for the Ariane space program. Even the Saudis, anxious to remain a supplier of chemical fuels in a post-fossil-fuel world, are laying plans for tapping solar energy to make hydrogen: They have signed an agreement with West Germany's aerospace agency DFVLR to build "Hysolar," a 100 KW prototype solar plant to produce hydrogen near Riyadh.

Today, the outlines of a triangular international hydrogen "consortium" involving West Germany, Japan and Canada is beginning to lay the foundations for the next century's non-polluting, regenerative global energy system.

Consider these recent developments:

- A Canadian government-sponsored study calls for the country to make hydrogen technology a "national mission." And the HIC is looking at the idea of experimentally "electrifying" railroad diesel engines with liquid hydrogen; using hydrogen-powered underground mining vehicles (of special concern because of underground environmental constraints); and exporting cheap electricity in the form of hydrogen to Europe and to Japan as rocket fuel for that country's space program.
- A German chemical-industry group, DECHEMA, under contract to the European Community, has completed a year-long pre-feasibility study of the idea of buying low-cost Canadian electricity, converting it in a 100 megawatt electrolyzer into hydrogen and shipping it as liquid hydrogen or in some other chemical compound in converted tankers to Europe for use in natural gas enrichment, making electricity and other applications.
- Two new solar-hydrogen research centers are being planned at Stuttgart and Ulm Universities, the latter in conjunction with carmaker Daim-

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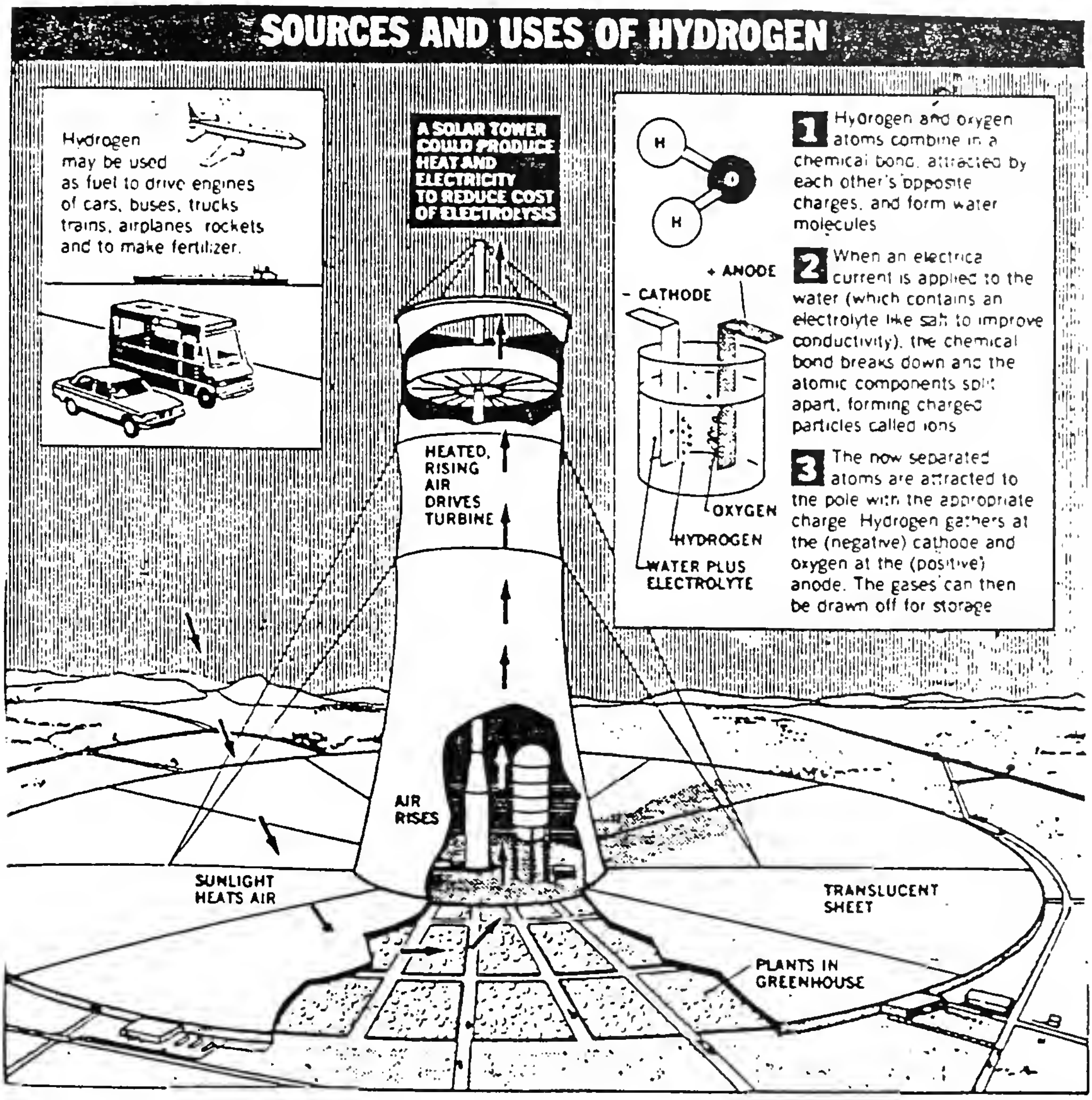
ler-Benz. Daimler-Benz, as part of a major corporate overhaul, has added hydrogen to its energy research agenda and is currently operating 10 hydrogen-powered station wagons and vans in an around-the-clock fleet test in West Berlin.

- Mercedes' arch-rival, BMW, has helped convert several cars to liquid hydrogen in a project started several years ago by the West German aerospace research agency. And the company is expected to become a partner in a project to build the world's first experimental solar-hydrogen plant in Bavaria.

- In Japan, researchers at the Musashi Institute of Technology in Tokyo over several years have developed liquid-hydrogen-powered diesel-type engines that are regarded the best applications yet available.

In the United States, some hydrogen work is going on at Texas A&M (with seed money from the National Science Foundation), the universities of Hawaii and Florida, Brookhaven National Laboratory and (due to start at some point in the future) the Solar Energy Research Institute in Colorado. What more the United States will do remains to be seen.

But "this country is on a collision course with another energy crisis," says Brown, "that could compare with the oil embargo of the 1970s." And hydrogen "may be the answer to our future energy needs."



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JOHNSTONE QUINAN—THE WASHINGTON POST

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Water to Burn B3

TODAY, HYDROGEN is made industrially—for such uses as petroleum refining, silicon crystal formation and fertilizer—chiefly by extracting it from natural gas in a process called steam-reforming, the most economical method so far.

But hydrogen can also be produced without the use of dwindling, polluting fossil fuels. The most common way is by electrolysis, which splits the water molecule into its component parts. When the elements combine, they release energy: Hydrogen and oxygen burn together, forming water and producing heat. Conversely, energy—in the form of electricity—must be applied to break up the molecule. Hydrogen bubbles up at the negatively charged cathode and oxygen at the positive anode. (See illustration above.) The quantity of water electrolyzed is proportional to the amount of current employed.

(If the process is reversed, the combination of hydrogen and oxygen produces a current, plus water. This is the principle of the fuel cell, which can function as a sort of battery. Used now in space vehicles, it may eventually power automobiles and trains.)

At present, hydrogen is relatively expensive to produce because of the energy costs involved. One method under development is electrolysis of steam at around 1,000° C, which requires less voltage than processing liquid water. But if the steam were produced by, say, concentrated energy from sunlight in a "solar tower" (see illustration) or other source, the price would fall.

Japanese and American laboratories have been looking for years for semiconducting materials that can use sunlight to make electricity which would in turn be used for electrolysis. Some designs use photovoltaic cells submerged in water in such a way that oxygen evolves on top, and hydrogen on the bottom. Other scientists are looking at hydrogen-producing photosynthetic bacteria common in tropical oceans.

Texas A&M's John Appleby thinks the way into a hydrogen economy is by extracting it from coal, but without the attendant carbon-dioxide pollution problems—perhaps through a modification of an existing California gasification system which is already being used to make clean (sulfur-free) hydrogen-rich gas. Part of the overall economics include selling or burying the unavoidable carbon dioxide byproduct so that it does not contribute to the greenhouse effect. "Based on what we know today," he says, "it would be cheaper than hydrogen produced via solar power."

In any event, hydrogen is not going to be cheap. But then no alternative fuels will be inexpensive in the post-fossil world. Appleby cites projections for hydrogen in the range of $45 per million BTUs (British thermal units, a measure of heat) in the mid-1990s—the equivalent of $6-per-gallon gasoline. But he also believes the California approach could produce hydrogen at about $9 per million BTUs, roughly equivalent to $1.35 gasoline, a price that does not include credits for the sale of carbon dioxide and electricity.

In fact, assuming more efficient fuel-cell cars in the future, the costs per mile might not exceed today's: Appleby says such a vehicle might operate at four times the efficiency of internal-combustion engines in urban use: "It has all the advantages of the electric car without the disadvantages of having to recharge the batteries."

—Peter Hoffmann

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STATEMENT OF HON. SPARK M. MATSUNAGA, A U.S. SENATOR FROM THE STATE OF HAWAII

Senator MATSUNAGA. Thank you very much, Mr. Chairman. I wish, first of all, to thank you for scheduling these hearings on three energy bills I have introduced in this 100th Congress and for inviting me to join with you after my testimony. And I do accept.

Senator FORD. Thank you.

Senator MATSUNAGA. The first two bills, Mr. Chairman, S. 1294 and S. 1295, both relating to fuel cell energy technology, were the subject of a full hearing before this subcommittee last year in February during the 99th Congress when I first introduced them. S. 1295, a bill to develop a national policy for the utilization of fuel cells, is identical to S. 1687 of the 99th Congress in the form. The measure was amended and reported favorably by the full Energy and Natural Resources Committee last year. Unfortunately, this bill was still on the Senate calendar at the time of adjournment.

Now, the third bill, S. 1296, to establish a national program of research, development and demonstration in the field of hydrogen, is a major piece of legislation which I have urged in the last three Congresses, and should be the primary focus of your hearing today as it is the first time that the measure has been the subject of hearing in the Senate.

Now, I have a separate statement to offer in this regard, Mr. Chairman, but first let me refresh the memory of senior members and acquaint new members of the subcommittee about my bills in support of fuel cell energy technology.

At the outset let me call your attention to the fact that these measures are cosponsored by Senator Weicker of the subcommittee, as well as by Senators Murkowski and Bingaman of the full committee, and by Senator Inouye, my colleague from Hawaii; and in the case of S. 1295, by Senator Hecht of your subcommittee.

Now, this is a technology pioneered in America. Although first constructed as an electrochemical device by Sir William Growe in 1839, the fuel cell had its initial practical application in the Gemini V flight of August 1965 where it proved to be an efficient, reliable power generator with very high energy density.

The device converts chemical energy derived from hydrogen rich gas combined with air into electricity without any intermediate combustion step. A typical cell produces high, direct current in a low voltage. Practical voltages are obtained by connecting many individual cells into what is referred to as a cell stack. The result has been hailed as the most efficient electrical generation device in existence.

Besides their high efficiencies, fuel cells offer a number of other advantages, including economy and size. They can be factory assembled, leading to short construction lead times, put on line in comparatively short periods. The capital outlay and interests costs can be expected to compare favorably. Output can be increased modularly as demand rises. The impact design means small, discrete increments of capacity allowing a better match of capacity to anticipated growth. Hence, this energy technology holds promise for both centralized and decentralized power systems.

Much effort has been expended in fuel cell research and development since the Gemini flight on the part of both the Federal Government and industry. This work has centered around various types of hydrogen fuel and cellular construction, as well as energy applications, including the use in electric hybrid vehicles.

The Federal R&D stake has grown to $335 million during the past 12 years according to the Congressional Research Service, and the investment of the Nation's gas utilities industries has been placed at another $100 million. The electric utilities and manufacturers, both large and small, have invested heavily also in this emerging technology which has gained increasing world attention. A successful 4 and a half megawatt fuel cell demonstration power plant to supply Tokyo Electric Power Plant has been constructed at Goyi, Japan by United Technologies Corporation, which completed trial testing of the plant at the end of 1985.

Now, this undertaking, in turn, was built upon an earlier prototype in New York City under the auspices of Consolidated Edison Company and the U.S. Department of Energy. It has led to the creation of a joint venture between United Technologies and the Toshiba Corporation entitled "International Fuel Cells," which has plans to commercialize an 11 megawatt fuel cell generator by late 1989.

The point of commercial payoff for the large investment, both public and private, in this technology, appears to be fast approaching. And my two measures are based upon a 1985 CRS survey of fuel cell developments which carried recommendations on bringing this public investment to fruition. The CRS report explained that the goal of Federal research in fuel cells since the mid-1970s has been to develop a highly energy efficient technology with some especially desirable characteristics for electric power planning, namely, low environmental impact, fuel flexibility, high performance, small size and spinning reserve capability.

The primary national gains expected from this research are increased fuel use efficiency, substitution of alternate fuels for conventional fuels, and development of a potential for improving our national balance of trade through the export of the technology.

The report noted that the Federal program had been built largely upon congressional initiatives, but has lacked a strategy for acting on the research findings. These two bills are designed to fill this gap.

Now, Mr. Chairman, inasmuch as these two bills have been the subject of hearings before this committee in the previous Congress, I would ask unanimous consent that the remainder of my testimony on these two measures be included in the hearing record as if presented in full.

Senator FORD. They will be included in full, Senator.

Senator MATSUNAGA. And of course, for the reasons I have stated, I urge your favorable report on S. 1294 and S. 1295 to expedite the advancement of this technology.

And now, Mr. Chairman, with your permission, I would like to testify upon my third bill, S. 1296, which is a bill to establish a national program of hydrogen research and development, a measure which Senator Evans of your subcommittee and I introduced in both the 98th and 99th Congresses. And in this, the 100th Congress, the two of us have been joined by Senator Inouye.

When I first introduced this bill in the 97th Congress, I had no other cosponsors. So, I feel my efforts in its behalf are now gaining momentum especially in light of the fact that there is now a companion bill in the House with four sponsors. And incidentally, hearings were held this morning over in the House, and I testified before that House committee.

Now, Mr. Chairman, I might say that this momentum comes none too soon with our preoccupation in this Congress regarding the Nation's competitive standing in the global marketplace. The urgency of establishing a national effort to advance the use of hydrogen energy is more clearly evident than ever before. This is because of the priority given to hydrogen R&D activity by such industrial nations as West German and Japan, as well as Canada, the Netherlands and Brazil. Canada has recently forged ahead in this field by emphasizing hydrogen production from water by electrolysis using electricity from nuclear, as well as hydropower plants. Yet here again, as with fuel cells, hydrogen energy represents a technology that was pioneered here in our own country, yet taken up by other countries.

Canadian industry and government support for hydrogen R&D totaled nearly $15 million last year. In Japan, the Ministry of International Trade is active in supporting hydrogen research, as well as related development work in photovoltaics and fuel cells. West Germany has a 15 year program which began in 1974 and runs through 1989 involving an annual investment of nearly $2 million in hydrogen research. The Netherlands, with its work in metal hydrides, and Brazil, where a 50-50 mixture of hydrogen and carbon monoxide is used as a substitute for natural gas, have ambitious programs, along with Austria, Sweden and Switzerland.

Hydrogen research is also being done in Egypt, Israel, Iran, the United Arab Emirates, Belgium, France, Italy, Denmark, and of course the Soviet Union.

Chinese scientists from the People's Republic have developed a type of multi-metal alloy capable of storing hydrogen gas as hydride that is said to be better and less expensive than comparable materials in the west.

The time for the United States to reassert its leadership role in the hydrogen field is now, Mr. Chairman. There should be no further delay. Too much is at stake. S. 1296 is designed to reclaim for the United States its original, preeminent position.

Hydrogen has long been hailed as the energy of the future, as the universal fuel, and the ultimate fuel which has the promise of creating a new economy. While this rhetoric may strike some as somewhat overblown, if not premature, there is increasing evidence that the present day applications of hydrogen as an energy storage medium and as a standby fuel in gas turbines suggest an energy source for the here and now, but one whose potential has yet to be realized. Certainly its advantages for aviation and space fuel are gaining increasing recognition on the part of both industry and government, especially in the development of trans-atmospheric aircraft as a priority of the Air Force and the Reagan Administration.

S. 1296, the Matsunaga-Evans-Inouye hydrogen R&D bill, is premised on carrying out the recommendations of various government reports on hydrogen as a fuel and energy source prepared by the National Academy of Sciences, the Department of Energy, and the General Accounting Office. A theme among these recommendations has been the necessity to have hydrogen production employ renewable or long-term primary energy sources. Their overriding conclusion, however, is that despite hydrogen's manifold advantages and benefits, it cannot be regarded as an energy option until the techniques of its generation, transmission and storage are explored to their full potential.

Now, this legislation addresses both concerns and would move us toward the use of hydrogen as an alternate fuel source through programs of accelerated research at the National Aeronautics and Space Administration and the Department of Energy. It is divided into two major titles, one having to do with hydrogen production and use, and the other focusing on hydrogen as a transportation fuel and specifically a fuel for aircraft and spacecraft.

Title I calls for a five year program management plan to be developed by the Secretary of Energy to include research priorities, technology strategies, cost estimates, and description of technology transfers in industry and academic participation. The bill contemplates R&D programs and hydrogen production, liquefaction, transmission, distribution, storage and use with priority given to techniques using renewables as the primary energy source. Small scale demonstration projects would be authorized, as well as plans for a large scale project complete with a feasibility assessment and implementation schedule.

The overall coordination for this program would be placed with the Energy Secretary aided by the technical support of NASA and the Department of Transportation. The Secretary would be required to consult with NASA, DOT and the Environmental Protection Agency, as well as the Hydrogen Technical Advisory Panel representing industry, academia and professional and scientific groups. Now, this panel would review the preparation and implementation of the program management plan, as well as the impact of any hydrogen systems deployment and report annually to the Energy Research Advisory Board on its findings.

The aggregate authorized funding during the five year period would be $100 million.

Title II would support consideration of so-called trans-atmospheric vehicles, or TAVs, such as the proposed Orient Express passenger plane. And I would observe in this connection, Mr. Chairman, that without a fuel possessing hydrogen's safety and power features, hypersonic aerospacecraft would be impossible to operate.

Under Title II, NASA's Administrator would be charged with developing a five year plan similar to that called for in Title I, but devoted to R&D and flight demonstration of a hydrogen-fueled aircraft. With the plan in hand, NASA would be required to report to Congress annually providing information on the necessary fuel production and ground support facilities for carrying it out. Participants would include DOT, DOE, EPA and a broadly represented Hydrogen- Fueled Aircraft Advisory Committee.

Authorizations for the five year plan under this title would also aggregate $100 million.

In connection with this title, Mr. Chairman, let me offer an aside in regard to hydrogen's safety properties. Although the Hindenburg dirigible disaster led to doubts on this score, experimental evidence indicates that there may be less hazard if liquid or hydrided hydrogen is used instead of jet fuel, gasoline, propane, kerosene or liquid methane. A tankful of jet fuel shot with a high-powered rifle would explode into flame, while a similar direct hit on a tankful of liquid hydrogen will only cause leakage. Now, this was amply demonstrated on 60 Minutes by the executive vice president of Lockheed several years ago. The properties of hydrogen which lead to this contradiction of popular expectation are at its low density, its high diffusion velocity in air and its emissivity.

In introducing this legislation, Mr. Chairman, I have stressed that this a bill which should draw support from all quarters, nuclear advocates and those concerned with the interests of both coal and natural gas, just as much as solar and renewable proponents, such as myself.

For those interested in advancing nuclear power, hydrogen can be seen as a vehicle for hurdling the safety barrier. Because energy is cheap to transport long distances with hydrogen as the storage medium and after 300 to 400 miles, increasingly cheaper than to transmit through electric wires, nuclear reactors could be located at greater distances from populated areas, even mounted on seaborne rigs. Injected into declining natural gas fields, hydrogen can serve as an enhancer stretching out the life of dwindling supplies

For those concerned with the interests of the coal industry, hydrogen also figures in an attractive scenario. If coal-gassed reactors were to be built at the seashore, they could eject carbon dioxide into the sea instead of into the air, and transmit energy in the form of hydrogen from coal. Now, this could give us perhaps another half century of coal availability without adding anything to the world greenhouse effect.

Now, hydrogen's appeal to solar proponents is apparent since it is environmentally benign. The main combustion product of hydrogen is water rather than carbon dioxide. Furthermore, the renewables represent the most promising sources for its production in terms of energy expended in the process. Finally, hydrogen is key to assuring continuity of supply for solar power by providing a ready storage medium whether overnight or until the clouds scatter in the sky.

With all these advantages for so many different energy quarters, this legislation should gain widespread support from the farsighted—like yourself, Mr. Chairman—of all camps.

Now, Mr. Chairman, for the reasons stated, I would strongly urge a favorable report on S. 1296. And I ask that the remainder of my statement be included in the hearing record as though presented in full.

Senator FORD. It, Senator, will be included in the record.

[The prepared statement of Senator Matsunaga follows:]

STATEMENT OF HONORABLE SPARK M. MATSUNAGA
A U. S. SENATOR FROM THE STATE OF HAWAII
BEFORE THE SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES,
SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT
IN REGARD TO S. 1296, A BILL FOR A HYDROGEN R&D PROGRAM
Dirksen Senate Office Building Room 366
Wednesday, September 23, 1987 - 2:00 p.m.

Mr. Chairman, my third bill on the subcommittee agenda here this afternoon is S. 1296, a bill to establish a national program of hydrogen research and development, a measure which Senator Evans of your subcommittee and I introduced in both the 98th and 99th Congresses. In this, the 100th Congress the two of us have been joined by Senator Inouye. When I first introduced this bill in the 97th Congress I had no other co-sponsors so I feel my efforts in its behalf are now gaining momentum, especially in light of the fact that there is now a companion bill in the House with four sponsors and it received a hearing this morning.

This momentum comes none too soon, Mr. Chairman. With our preoccupation in this Congress regarding the nation's competitive standing in the global marketplace, the urgency of establishing a national effort to advance the use of hydrogen energy is more clearly evident than ever before. This is because of the priority given to hydrogen R&D activity by such industrial nations as West Germany and Japan, as well as Canada, the Netherlands and Brazil. Canada has recently forged ahead in this field by emphasizing hydrogen production from water by electrolysis, using electricity from nuclear as well as hydro power plants. Yet here again, as with fuel cells, hydrogen energy represents a technology that was pioneered here in our own country.

Canadian industry and government support for hydrogen R&D totalled nearly $15 million last year. In Japan the Ministry of International Trade is active in supporting hydrogen research as well as related development work in photovoltaics and fuel cells. West Germany has a 15 year program which began in 1974 and runs through 1989 involving an annual investment of nearly $2 million in hydrogen research. The Netherlands, with its work in metal hydrides, and Brazil, where a 50-50 mixture of hydrogen and carbon monoxide is used as a substitute for natural gas, have ambitious programs, along with Austria, Sweden and Switzerland. Hydrogen research is also being done in Egypt, Israel, Iraq, the United Arab Emirates, Belgium, France, Italy, Denmark, and of course the Soviet Union. Chinese scientists from the Peoples Republic have developed a type of multi-metal alloy capable of storing hydrogen gas as hydride that is said to be better and less expensive than comparable materials in the West.

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Hydrogen has long been hailed as the "energy of the future," as the "universal fuel" and the "ultimate fuel" which has the promise of creating a "new economy." While this rhetoric may strike some as somewhat overblown if not premature, there is increasing evidence that the present-day applications of hydrogen -- as an energy storage medium and as as a standby fuel in gas turbines -- suggest an energy source for the here-and-now, but one whose potential has yet to be realized. Certainly, its advantages for aviation and space fuel are gaining increasing recognition on the part of both industry and government, especially in the development of "trans-atmospheric aircraft" as a priority of the Air Force and the Reagan Administration.

S. 1296, the Matsunaga-Evans-Inouye hydrogen R&D bill, is premised on carrying out the recommendations of various government reports on hydrogen as a fuel and energy source prepared by the National Academy of Sciences, the Department of Energy, and the General Accounting Office. A theme among these recommendations has been the necessity to have hydrogen production employ renewable or long-term primary energy sources. Their over-riding conclusion, however, is that despite hydrogen's manifold advantages and benefits, it cannot be regarded as an energy option until the techniques of its generation, transmission, and storage are explored to their full potential.

This legislation addresses both concerns and would move us toward the use of hydrogen as an alternate fuel source through programs of accelerated research at the National Aeronautics and Space Administration (NASA) and the Department of Energy (DOE). It is divided into two major titles, one having to do with hydrogen production and use and the other focusing on hydrogen as a transportation fuel and, specifically, a fuel for aircraft and spacecraft.

Title One calls for a five year program management plan to be developed by the Secretary of Energy to include research priorities, technology strategies, cost estimates and descriptions of technology transfer and industry and academic participation. The bill contemplates R&D programs on hydrogen production, liquefaction, transmission, distribution, storage and use -- with priority given to techniques using renewables as the primary energy source. Small scale demonstration projects would be authorized, as well as plans for a large scale project complete with a feasibility assessment and implementation schedule. The overall coordination for this program would be placed with the Energy Secretary aided by the technical support of NASA and the Department of Transportation (DOT). The Secretary would be required to consult with NASA, DOT, and the Environmental Protection Agency, as well as a Hydrogen Technical Advisory Panel representing industry, academia, and professional and scientific groups. This panel would review the preparation and implementation of the program management plan as well as the impact of any hydrogen systems deployment and report annually to the Energy Research Advisory Board on its findings. The aggregate authorized funding during the five year period would be $100 million.

Title Two would support consideration of so-called "trans-atmospheric vehicles" or TAVs, such as the proposed "Orient Express" passenger plane, and I would observe in this connection, Mr. Chairman, that without a fuel possessing hydrogen's safety and power features, hypersonic aerospacecraft will be impossible to operate. Under Title Two, NASA's Administrator would be charged with developing a five year plan similar to that called for in Title One but devoted to R&D and flight demonstration of a hydrogen-fueled aircraft. With the plan in hand, NASA would be required to report to Congress annually, providing information on the necessary fuel production and ground support facilities for carrying it out. Participants would include DOT, DOE, EPA and a broadly representative Hydrogen-Fueled Aircraft Advisory Committee. Authorizations for the five year period under this title would also aggregate $100 million.

In connection with this title, Mr. Chairman, let me offer an aside in regard to hydrogen's safety properties. Although the Hindenburg dirigible disaster led to doubts on this score, experimental evidence indicates that there may be less exposure to hazard if liquid or hydrided hydrogen is used instead of jet fuel, gasoline, propane, kerosene, or liquid methane. A tankful of jet fuel shot with a high-powered rifle will explode into flame, while a similar direct hit on a tankful of liquid hydrogen will only cause leakage. The properties of hydrogen which lead to this contradiction of popular expectation are its low density, its high diffusion velocity in air, and its emissivity.

In introducing this legislation, I have stressed that this is a bill which should draw support from <u>all</u> quarters: nuclear advocates and those concerned with the interests of both coal and natural gas just as much as solar and renewable proponents such as myself. For those interested in advancing nuclear power, hydrogen can be seen as a vehicle for hurdling the safety barrier. Because energy is cheap to <u>transport</u> long distances with hydrogen as a storage medium, and, after 300 to 400 miles, increasingly cheaper than to transmit through electric wires, nuclear reactors could be located at greater distances from populated areas -- even mounted on seaborne rigs. Injected into declining natural gas fields, hydrogen can serve as an "enhancer," stretching out the life of dwindling supplies.

For those concerned with the interests of the coal industry, hydrogen also figures in an attractive scenario. If coal-based reactors were to be built at the seashore, they could eject carbon dioxide into the sea, instead of into the air, and transmit energy in the form of hydrogen from coal. This could give us perhaps another half century of coal availability, without adding anything to the world greenhouse effect.

Hydrogen's appeal to solar proponents is apparent, since it is environmentally benign. The main combustion product of hydrogen is water, rather than carbon dioxide. Furthermore, the renewables represent the most promising sources for its production in terms of energy expended in the process. Finally, hydrogen is the key to assuring continuity of supply for solar power by providing a ready storage medium, whether overnight or until the clouds scatter in the sky.

With all these advantages for so many different energy quarters, this legislation should gain wide-spread support from the far-sighted of all camps. Indeed, hydrogen is hailed by environmental scientists as a "clean energy" solution to the problem of acid rain as well as the "greenhouse" impact on the earth's atmosphere. The Clean Energy Research Institute of the University of Miami recently issued a report which suggests that hydrogen fuel offers the key to resolving differences between the United States and Canada regarding the acid rain issue.

Needless to say, Mr. Chairman, my home State of Hawaii, which is highly dependent upon imported oil but which enjoys an abundance of sunlight, seawater and geothermal power that can be applied to hydrogen production through solar and ocean thermal conversion techniques, has a great stake in the development of hydrogen as an energy source and an energy storage medium.

But hydrogen's advantages are universal in their application, as a replacement for both electricity and conventional fuels. Combined in a fuel cell with the atmosphere, electricity is produced; burned in a stove or engine, heat or mechanical motion can be extracted; stored in hydride form, a vehicle can be powered; and cooled into a liquid state, it is the safest, ideal transportation fuel which produces much higher energy per unit of weight than conventional jet fuel. Hydrogen's advantages over electricity are many in terms of storage applications and ease of transmission. Experimental evidence attests to the comparative safety of hydrogen in liquid or hydride form, as I have mentioned. Indisputably, it has clear-cut environmental advantages.

Finally, Mr. Chairman, not the least of hydrogen's many advantages is the abundance of its primary feedstock. In recent months we have witnessed world tensions in the Persian Gulf over access to crude oil. It is difficult to imagine similar tensions over access to such "free goods" as seawater and sunlight. In this light, hydrogen can be seen not as a "free good," but a most precious resource for us all: a universal fuel for the promotion of peace on our planet.

Some years ago we heard much about a pervasive future "hydrogen economy." At that time, it was observed that hydrogen fuel is virtually inexhaustible as well as clean burning, convenient, versatile -- and free of foreign control. This reasoning has lost none of its cogency since then. I submit, Mr. Chairman and members of the Subcommittee, expeditious action on S. 1296 to accelerate the commercialization of hydrogen will be a big step toward forestalling future energy crises.

Thank you.

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Senator FORD. Senator, I think you explained your position on all three pieces of legislation. We have discussed those, and I would have no questions for you at this time.

Senator MATSUNAGA. Thank you.

Senator FORD. If you wish to join me here, it would be fine.

The first panel of witnesses today will be the Assistant Secretary for Conservation and Renewable Energy, U.S. Department of Energy, Donna R. Fitzpatrick. She will be accompanied by Deputy Assistant Secretary for Renewable Energy, Robert L. San Martin; and the Acting Director, Propulsion, Power and Energy Division, NASA Headquarters, Mr. Gregory M. Reck.

And Madam Secretary, we will ask that you go first. Will Mr. San Martin be making any kind of a statement?

Miss FITZPATRICK. No.

Senator FORD. Fine.

Miss Fitzpatrick.

STATEMENT OF DONNA R. FITZPATRICK, ASSISTANT SECRETARY FOR CONSERVATION AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY, ACCOMPANIED BY ROBERT L. SAN MARTIN, DEPUTY ASSISTANT SECRETARY FOR RENEWABLE ENERGY

Miss FITZPATRICK. Thank you, Mr. Chairman.

I have a full statement which I would like inserted in the record, if I may.

Senator FORD. You certainly may, and highlight your statement. It would be just find.

Miss FITZPATRICK. Thank you. I am accompanied by Dr. Robert San Martin, who is Deputy Assistant Secretary for Renewable Energy.

We appreciate the opportunity to appear before the subcommittee today to discuss the Department of Energy's hydrogen and fuel cell programs and the proposed legislation relating to them. I will begin with our hydrogen program.

At the present time hydrogen is used almost entirely as a unique industrial chemical in petroleum processing and in the synthesis of ammonia and methanol. This represents about 90 percent of its industrial use. Other uses of hydrogen range from the production of foodstuffs, such as margarine, to its use as a high energy rocket fuel.

Hydrogen is certainly an abundant element, but it does not occur in nature in the free elemental state. Therefore, it is not a primary energy source and must always be manufactured. It must be recognized that as a secondary energy form, the energy to be derived from hydrogen will always be less than the energy which was required to produce it. This energy consumption is quite substantial. It currently requires from 4 to 15 units of raw energy to manufacture 1 unit of hydrogen energy. Today hydrogen is produced in a variety of processes, but it must be remembered that the resulting hydrogen comes from the consumption of some fuel, such as coal or natural gas and, therefore, the hydrogen which results cannot be as energy efficient as using the primary fuel. Therefore, if hydrogen as an energy carrier is to be used in other than specialty applications, we need significant technology improvements in a number of areas, and the Department is carrying out and plans to continue to carry out a research program to address the technical issues in those areas.

On the subject of fuel cells, these are energy conversion devices that convert chemical energy directly to electrical energy without the inherent inefficiencies of going through a thermal cycle. They are powered by the electrical-chemical combination of hydrogen and oxygen.

The advantages of fuel cells include their high efficiencies as compared to internal combustion engines, their ability to use non-petroleum fuels, and improved environmental effects. Fuel cells have potential applications in transportation, in residential and commercial buildings, industry, and utilities. The most efficient type of fuel cell for these uses would be one that would oxidize organic fuels rather than process these to hydrogen which would then be oxidized in the electrochemical cell.

The real bottom line with respect to the economics of fuel cells for terrestrial versus space applications is going to be the cost of electricity generated which, in turn, will depend on the capital costs of the equipment, on the efficiencies of the equipment, and on their lifetime and reliability.

The factors that impede the commercialization of fuel cells are that we still need to see improvements in the areas of initial cost, lifetime and efficiency of performance. By addressing these issues, the DOE research programs will improve the base technology to the point where industry can develop commercial prototypes.

Our current hydrogen research and fuel cell programs have been carefully fashioned, and we believe that they, along with our other research efforts, will carry out the intent of the proposed legislation and will continue to expand the range of technical options available to the market to improve our Nation's energy future.

Mr. Chairman, we appreciate the advice we have received from the Congress and, in particular, this subcommittee, and we thank you for the opportunity to appear today.

[The prepared statement of Miss Fitzpatrick follows:]

Statement of

Donna R. Fitzpatrick
Assistant Secretary
for
Conservation and Renewable Energy

U.S. Department of Energy

to the

Senate Committee on Energy and Natural Resources
Subcommittee on Energy Research and Development

September 23, 1987

Mr. Chairman and Members of the Committee:

Thank you for the opportunity to appear before you today to discuss the Department of Energy's hydrogen and advanced fuel cell programs, and the Senate bills S. 1294 and S. 1296 relating to hydrogen and fuel cells.

OVERVIEW ON HYDROGEN

Hydrogen is an abundant element but it does not occur in Nature in the pure state. It has been known to man for about two centuries. It was initially used as a buoyant gas, then as a synthetic-fuel constituent. At present, hydrogen is used almost entirely as a unique industrial chemical in petroleum processing and in synthesis of ammonia and methanol.

In addition to the dominating applications in petroleum refining, ammonia synthesis for fertilizer production, and methanol manufacturing, hydrogen as a chemical has a range of miscellaneous and special uses. Hydrogen is used in the production of foodstuffs, including margarines and cooking fats, and in the manufacture of soap. It serves in the refining of certain metals, in semiconductor manufacture, and for the annealing of metals. It is employed in uranium extraction and processing and for corrosion control in nuclear reactors. Hydrogen also cools electrical generators in utility power stations and is a feedstock in organic chemical synthesis leading to production of nylon and polyurethane. It is a high energy rocket fuel and an experimental aviation and automotive fuel. The use of hydrogen in each of these applications is quite specialized, but they illustrate the range of industrial uses that already exist.

Hydrogen is not, however, a primary energy source--it must be manufactured. Practically all the hydrogen now produced in this country is manufactured from natural gas and light oils. It must be recognized that as a secondary energy form, the energy to be derived from hydrogen will always be less than the energy required to produce it.

Since hydrogen does not exist on earth in its elemental form, to obtain hydrogen requires conversion of compounds containing hydrogen. This conversion requires energy sources such as coal, solar, or nuclear to be consumed to be able to produce hydrogen. This energy consumption is substantial, currently requiring from 4 to 15 units of raw energy to manufacture 1 unit of hydrogen energy, depending on whether the product is gaseous, liquid, or "slush". Therefore, hydrogen technology represents only a potential bridge between energy sources such as solar, nuclear, and coal and energy consumers such as the various applications mentioned earlier. This is similar to the existing electric power grid or the battery technologies under development. To determine whether widespread use of hydrogen should take place, the complexities, energy cost, and dollar cost associated with changing our energy production and distribution network must be addressed.

From an energy perspective, the question is not whether the Nation can use hydrogen for many applications now served by electricity or other energy carriers, but should we use it in this way. It is technically possible to connect almost any source to any energy use by means of hydrogen. Our judgment on whether to use this bridge should be governed by the total cost to society. When it becomes more convenient and more economical, it will be used.

RATIONALE FOR HYDROGEN RESEARCH

Today hydrogen can be produced via a number of processes, but it must be remembered that the resulting hydrogen comes from the consumption of other fuel sources and, therefore, cannot be as energy efficient as using the primary fuel. Therefore, if hydrogen is to be used in a greater variety of applications, improvements will be required in several areas to improve the efficiency of hydrogen production. Also, more effective storage systems for both bulk and mobile will be required.

For the production of hydrogen, water electrolysis is the most mature of the water-splitting technologies in use by industry. In DOE sponsored work, advances have been made in electrocatalysis, electrode materials, separators, and electrolytes. Research is still needed to reduce capital cost and maximize reliability for large-scale systems. New developments in water vapor electrolysis conducted at temperatures up to 100 C, promise overall efficiency improvements of 30%-50% over lower temperature water electrolysis technology. Other techniques of water splitting, such as photochemical or biological processes, are infant technologies that show promise for the long term.

Hydrogen can also be produced from coal, natural gas, or renewable sources (wind, ocean). Production from natural gas is the least expensive; costs for other sources can be three to 30 times higher, largely because of the energy consumed by the production process. Therefore, an inexpensive renewable energy source could be the key to the economically competitive production of hydrogen. This suggests that continued research to improve the technology base of renewable energy conversion systems is itself an important step in promoting increased hydrogen use.

Hydrogen storage continues to be a problem. It has been suggested that long-term bulk storage of hydrogen can take place in depleted oil wells and caverns but extensive testing has not been conducted. For mobile applications, metal hydrides -- where hydrogen is temporarily chemically bound to a porous metal matrix -- have been investigated but this form of storage today is an expensive alternative to compressed gas and liquefied hydrogen.

Hydrogen embrittlement of conventional pipeline steels is recognized as a primary deterrent to hydrogen transport at high pressures. Fundamental investigations have verified the embrittlement phenomena and studies have been extended toward identification of embrittlement suppression techniques. Recent investigations have shown that introduction of oxidants as low-concentration additives to hydrogen streams may offer means for suppressing embrittlement.

S. 1296

Let me turn first to specific comments on the Senate bill on hydrogen, specifically Title 1 of S. 1296, pertaining to the Department of Energy.

The intentions of the bill are good. To prepare for the future is both wise and prudent. This is also the goal of the Department in carrying out its research into ways to produce and store hydrogen, along with other energy technologies that may serve the same purpose.

As stated, considerable progress has been made in understanding just what is needed to have hydrogen as an alternative energy carrier in the future. Our research is continuing to find improvements in producing, storing, and transporting hydrogen for transportation, process heating, fuel cells, and other applications.

The DOE plans to continue its research and development in hydrogen and believes that the spirit of the proposed legislation can be carried out through its existing program. New legislation is, therefore, not required to accomplish the intent of S. 1296, Particularly in a time of tight budgets, we believe taxpayer dollars are best spent on longer range, more generic research that benefits all areas of hydrogen production, storage, and transportation. Until these fundamental issues are resolved, demonstration and commercialization activities (which are more appropriately the province of the private sector) will not efficiently provide significant progress toward achievement of the objective of S. 1296. Clearly, the Government can provide the most effective contribution by establishing a technology base on which industry can build. Our current hydrogen research has been carefully fashioned to ensure that tax dollars are not supplanting private sector funding. We will continue to make available to the private sector the results of our technology base research and we will encourage them to exploit this knowledge. The Department of Energy is continuing to expand the range of technical options available to the private sector, including the use of hydrogen, that will improve our Nation's energy future. For these reasons, we do not support this legislation.

I have included in my testimony two attachments, one which further describes the Department of Energy's hydrogen-related research in the Office of Basic Energy Sciences and a second one which elaborates on the Chemical/Hydrogen Energy Storage project in the Office of Energy Storage and Distribution.

Let me turn now to the area of advanced fuel cells, and Senate bill S. 1294 which relates to fuel cells.

OVERVIEW OF ADVANCED FUEL CELLS

The DOE fuel cell program can trace its origins to work that began more than two decades ago in laboratory and special applications research. Today this effort has evolved into a multi-faceted research program. The Office of Conservation and Renewable Energy currently oversees research on Phosphoric Acid fuel cells for transportation applications and manages research on Solid Polymer Electrolyte fuel cells - also known as Proton

Exchange Membrane (PEM) fuel cells. The future application for the latter technology will be predominantly for mobile, and remote.

This multi-pronged effort is internally coordinated, with all elements of the Department exchanging results and future plans on a regular basis.

Technology Descriptions

Fuel cells are energy conversion devices that convert chemical energy directly into electric energy without the inherent efficiency limits of heat engine cycles. A complete fuel cell power plant would typically include a fuel processing section (such as a reformer or a coal gasifier section with gas cleanup), a power producing section (often referred to as the fuel cell stack), and a power processing section with a direct-current-to-alternating current invertor.

Fuel cells are powered by the electrochemical combination of hydrogen and oxygen. The source of hydrogen can vary considerably; virtually any hydrocarbon fuel can be a potential feedstock for a fuel cell power plant, although for economic reasons, coal, natural gas, other sources of methane and methanol will likely be the principal fuels.

Higher operating temperatures may provide significant efficiency and capital cost advantages; however, elevated temperatures are not suitable for all potential fuel cell applications. In particular, the choice of a fuel cell for some mobile applications may be dictated, in large part, by the need for a system capable of operating at reduced temperatures, i.e., the phosphoric acid or proton-exchange-membrane technology. Other concepts in the very early development phases (such as the monolithic solid-oxide concept) may offer low-weight and low-volume systems compatible with some mobile applications.

Applications and Research Emphasis

Programs are in progress at Brookhaven National Laboratory and at Los Alamos National Laboratory (LANL) for the investigation of fuel cells for vehicular propulsion. Some of the above advantages of fuel cell power plants over thermal ones for electric and gas utility power generation apply equally well for vehicular power plants. The significant one is that the projected efficiencies for fuel cells are at least twice as high as those for internal combustion and diesel engines.

Transportation's share of petroleum use in the United States reached 64% in 1986. This figure represents 108% of domestic production and indicates the impact that changes in the transportation area can have on petroleum needs. The objective of the fuel cell work at LANL is to help reduce U.S. dependency on petroleum resources and to provide full performance vehicles. Fuel cells possess a number of attributes that make them very attractive for transportation applications. Their high efficiency and ability to use non-petroleum fuels address the petroleum dependency problem. Their operational simplicity, safety, and low pollution are features that make them desirable for use in cars and trucks. The fuel cell system chosen for a given application must be selected on the basis of performance and of type of fuel required. Based on the state-of-development, fuel considerations, and the inherent restrictions imposed by vehicular applications, only acid fuel cells, phosphoric acid (PA) and proton exchange membrane (PEM), operating on reformed methanol and air are being considered at the present time. The PA fuel cell is the choice for near-term use, because it represents the only technology that has demonstrated full-stack operation on reformed fuel. The potential of the PEM fuel cell in terms of high power density, low-temperature operation, rigid and contained electrolyte, and cold start capability dictated its consideration, even though the system technology development is immature for terrestrial operation on reformed fuel.

In summary, simulation studies indicate that it is feasible to use fuel cell or fuel cell/battery hybrids in city buses and in passenger cars. Improvements in technology should enhance this feasibility of using fuel cells in transportation. Fuel cell use in the transportation sector will depend upon the success of ongoing research efforts to overcome constraints on cost, size, and operating conditions.

Another area of fuel cell application, sponsored by the American Gas Association, is the residential and commercial buildings sector. Strong interest by the gas utilities is evidenced by the recently completed field test of nearly fifty 40-kilowatt power plants producing electricity and cogenerated heat. Introduction of commercial gas-using fuel cells in this sector is expected in the 1990s. Due to the smaller size required of fuel cell power plants for the residential sector, (several kW), and also because of competitive economic constraints, fuel cells are unlikely to find application in the residential sector in the immediate future. Use of feedstocks such as coal or biomass in these applications will likely depend upon the economic competitiveness of processes to convert these fuels into pumpable gaseous or liquid products and the existence of suitable delivery systems.

Fuel cell use in the industrial sector could follow introduction in the electric utility sector and basically rely on modules similar to those being developed for electric utility plants.

Renewable Fuel Cell Program

Solid Polymer Electrolyte Fuel Cell Systems: This system is being considered for transportation applications. Because the system operates at less than 100 C, methanol is the most appropriate liquid fuel to be reformed and used in this fuel cell system. Progress had been made at Los Alamos National Laboratory to reduce the noble metal, e.g., platinum, loading to one-tenth that of the previous state-of-the-art system. This is done by incorporating a proton conductor into the electrode structure to extend the three-dimensional reactor zone. Water management can be achieved by optimum humidification of the system. Prospects are good for attaining high power densities (those over 500 mW/cm^2).

Direct Methanol Fuel Cell: A fuel cell researcher's dream is to oxidize organic fuels (preferably methanol, which can be produced from biomass or coal) rather than to process these to hydrogen, which is, in turn, oxidized in the electrochemical cell. Methanol is the most active electro-organic fuel, but its activity is 3 orders-of-magnitude less than that of hydrogen. Thus, under these conditions, current-densities of about 50 mA/cm^2 are obtained at cell potentials of 0.4 V, somewhat lower than desired. Even at these current densities, there is a performance degradation with time. The main cause for the degradation is that the intermediates formed during methanol oxidation poison the platinum electrocatalyst. The poisoning effects are less with some alloy electrocatalysts (e.g., Pt-Ru, Pt-Sn) and with platinum electrocatalysts with additional atoms such as Bi, Pb, Sn, Ge.

Prognosis of Economics and Applications of Fuel Cell Systems

The applications of fuel cell systems have been well-demonstrated in space vehicles. Capital costs are not such an overriding factor for space applications as they are for terrestrial applications. The alkaline, and possibly the solid polymer electrolyte fuel cell, systems will continue to be the auxiliary power sources for space vehicles. The present price of crude oil makes it more difficult to introduce fuel cell systems into the terrestrial arena. On the other hand, environmental constraints can also accelerate the entry of fuel cell technologies.

The bottom line with respect to economics of fuel cells for terrestrial applications will be the cost of electricity generated, which, in turn, will depend on capital costs, efficiency, and life-time. Taking into consideration the performances of fuel cells for terrestrial applications, the major factors to be overcome are: (1) development of automated techniques to reduce the capital costs of the system; (2) achievement of reliability of performance over the required lifetimes; (3) demonstration of economic, technical, and environmental advantages of dispersed, on-site integrated energy and cogeneration power plants; and (4) development of a niche for electric vehicles - in plants, military uses, buses, trucks, and automobiles.

The factors that impede the commercialization of fuel cells are that improvements are needed in the areas of initial cost, lifetime and performance. More specific barriers are the high cost of electrocatalysts and porous electrodes; the corrosion of active and passive cell components; instabilities of porous electrode

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structure under long-term cycling; loss of electrocatalytic activity with time and use; inadequate conductivity of electrolytes for high-performance (power) application and lack of advanced electrodes and cell-designs for high-performance applications. By addressing these issues the DOE programs will improve the base technology to the point where industry can develop commercial prototypes.

S. 1294

The purpose of the bill, stated as "exploring the operation of fuel cells employing methane gas generated from various forms of biomass", will be a good match with the type of fuel cell and fuel processor being developed. The focus is on solid polymer electrolyte fuel cells, because they offer the potential for higher power density fuel cells; they tolerate carbon dioxide in the fuel streams, and therefore can use reformed methane, methanol, or hydrogen; and they operate below one-hundred degrees centigrade, allowing low temperature startup and use of low-cost structural material. The operation of cells on reformed methanol and hydrogen is currently being investigated and the prototype fuel cells will also be tested with reformed methane.

As I have explained, production of hydrogen by water electrolysis and photoelectrochemical methods are part of the hydrogen program. Hydrogen is currently used as a fuel cell fuel. Currently there are no activities related to the third purpose of the bill, "determining the technical requirements for employing fuel cells for power production as backup spinning reserve components to renewable power systems in rural and isolated areas." This is an area that should be carried out in the future but currently has a low priority because of the immaturity of the technology.

Where government can provide the most effective contribution to fuel cell technology is in building a solid base of technological information which industry can use to make market-oriented, developmental decisions.

Our current fuel cell program, particularly as it is presented within the President's Fiscal Year 1988 budget request, has been carefully fashioned to ensure that tax dollars are not supplanting private sector funding. We will continue to make available to the private sector the results of our technology base research and will encourage them to implement this research when market forces dictate.

The Department of Energy is committed to expanding the range of technical options available to the private sector that will improve our Nation's energy future; fuel cells are a sound prospect for this future. Current programs are adequately funded to address the intent of these bills. Any future activities will be considered as part of the budget process. For this reason, we do not think this legislation is necessary. As I indicted previously, the remaining pages of our testimony provide more details on the ongoing fuel cell efforts with the Department of Energy.

Thank you for the opportunity to discuss this area of research with you today.

ATTACHMENT 1

HYDROGEN-RELATED RESEARCH

The Office of Basic Energy Sciences (BES) supports long-range basic energy-related research and is charged with providing the fundamental scientific foundation for the Nation's future energy options. Accordingly, some of the 1400 individual research projects in the areas of physical and biological sciences, engineering, and geosciences are related to DOE's interests in hydrogen. The hydrogen-related research supported by BES is found largely in the divisions of Chemical Sciences, Materials Sciences, and Energy Biosciences. In almost all cases, the research is long range and generic with very little research being focused directly on a specific energy technology.

The Chemical Sciences research includes basic solar photochemistry, biomass chemistry related to dissociation of water, and hydride research for the storage of hydrogen. The focus of the Chemical Sciences programs as it relates to hydrogen is on the fundamental understanding of the chemistry involved in production and storage concepts at the most basic level.

In our fundamental research program in solar photochemistry energy conversion, fundamental processes are being explored which can be applied to hydrogen production by splitting the water molecule into its components, hydrogen and oxygen, to methanol production from carbon dioxide, ammonia synthesis from atmospheric nitrogen, or to production of other needed chemicals at lower energy cost by using sunlight. The research is expected to provide the basis for new solar chemical technologies in the distant future.

Solar photochemistry research is proceeding on several fronts. In plant and bacterial photosynthesis research, the emphasis is on understanding how sunlight initiates the primary steps of photosynthesis at the molecular level. This insight is being used to design simple molecules which can absorb light and use its energy to separate charges long enough to drive useful chemical reactions. Other research involves photocatalytic chemical reactions in homogeneous and heteorogeneous systems. Particularly noteworthy in this area are metal catalyst-coated semiconductor colloidal particles in solution, where product separation may be achieved by vesicles or bilayer membranes. Other reaction systems involve photosensitization by porphyrins or other visible light-absorbing chromophores. The key to success in the design of these systems is more efficient electron transfer in the forward direction than the reverse, which necessitates careful mechanistic and kinetic experiments. Photoelectrochemistry is perhaps the most advanced area of solar photochemistry research, although no known semiconductor is the perfect candidate. Semiconductor electrodes which absorb in the visible region must be protected from photocorrosion in aqueous solution, which is being achieved by coatings of transparent conducting polymers. Other semiconductors which are photostable in water but absorb outside the visible region are being modified with pendant chromophores photocatalysts to drive the chemical reactions of interest.

Other efforts in chemical sciences include the study of photosynthetic evolution of hydrogen from biomass systems using enzyme catalytic processes and the chemical aspects of hydrogen storage in hydride systems. The latter includes the determination of thermochemical properties and structural parameters to understand their behavior on hydriding characteristics.

The Materials Sciences programs related to hydrogen are focused on obtaining a fundamental understanding of the interactions of hydrogen with materials. These programs are, therefore, necessarily basic or generic in character and do not directly engage in the development of specific technologies for a hydrogen economy. They do, however, provide fundamental understanding necessary for the development of these and other related technologies; for example, technologies related to hydrogen storage, end-use, and synfuel production. Specifically, research is underway on diffusion of hydrogen in rare earth, on refractory metal alloys, on the uptake and the thermodynamics and kinetics of hydrogen in noble metals, on behavior of hydrogen on metal surfaces, on a theoretical understanding of the effects of hydrogen on bonding in metals, on hydrogen attack, on a phenomenon that occurs in some steels subjected to high-temperature, high-pressure hydrogen as a coal gasification process, and on protonic conduction in solid electrolytes as might be encountered in batteries or fuel cells.

The Division of Energy Biosciences supports research aimed at understanding the mechanisms involved in the biological production and utilization of molecular hydrogen. The long-term objective of the program is to provide the requisite scientific foundation for the development of novel biotechnologies based on hydrogen as an energy resource or ones in which hydrogen plays an integral role in the production of other products such as methane. The emphasis of the research supported is on the bioenergetics of hydrogen production and the enzymes, the hydrogenases, responsible for the production of hydrogen driven by light energy directly or indirectly through renewable plant resources. The related hydrogenases responsible for the transfer of hydrogen between species of anaerobic bacteria is also a research area supported. Effort also focuses on understanding the group of enzymes which are responsible for hydrogen production, hydrogen transfer, or hydrogen utilization. Their molecular structure, genetic and metabolic regulation mechanism of action, oxygen liability, and involvement of metals are all subjects of investigation.

ATTACHMENT 2

CHEMICAL/HYDROGEN ENERGY STORAGE PROGRAM

Background

For the past decade, DOE has pursued mission-oriented hydrogen technology development. These programs concentrate on long-term technology-base developments geared to conversion, storage, and transport.

PROGRAM RATIONALE AND STRATEGY

Chemical/hydrogen energy systems (C/HES) are identified as a candidate link between renewable primary resources and energy demand sectors. Current economics and the availability of conventional energy resources place the exercise of the C/HES option well into the far term. Therefore, a long-range program has been structured to develop a technology base across the full spectrum of conversion/production, storage, and transport technologies. The R&D investment is viewed as increasing the flexibility to accommodate a different mix of energy supply sources in the future.

Cost Performance Objectives

The versatility of hydrogen as a fuel and chemical commodity and its environmentally benign characteristics have been well documented. It remains for a technology base to be developed which will effectively establish cost effective benefits. Conversion of various resources to a secondary chemical energy form, such as hydrogen, calls for achieving high conversion efficiencies at minimal capital outlay. Effective storage of this chemical energy in bulk and mobile systems is required to offset energy supply-demand mismatches and to provide on-board energy storage options for vehicular transport.

The conversion, storage, and transport requirements have been translated to specific cost and performance objectives for each element of the program.

- o Hydrogen Production Cost -- \$10/MMBtu (1980 dollars)
- o Storage Cost -------------- \$1-3/MMBtu (1980 dollars)
- o Storage Density ----------- Greater than 4% by weight for metal hydrides or 2500 BTU's per lb.
- o Transport ---------------- Long-Term Stability (conventional pipeline)

Technology State-of-the-Art

Hydrogen Production - Historically, this segment of the program has been concerned with developing alternatives to steam reforming of natural gas for the production of hydrogen, with emphasis placed mainly on the dissociation of water via electrolysis. Energy used for dissociating water can be in the form of heat or electricity. Since Carnot limitations of steam cycles used to produce electricity imply an efficiency ceiling, it would appear prudent to pursue the direct utilization of heat in water-splitting processes. Thermal decomposition processes operating in the extreme temperature regimes (greater than 3000 C) do not bode well with regard to materials availability and process simplicity. Substantial efforts in the past have been directed toward identifying thermochemical cycles which could alleviate some of the process engineering difficulties; however, materials handling, corrosion, and process complexity remain major problems.

Technical judgments suggest that a combination of thermal and electrochemical processes can be optimized via development of high-temperature (300C-1000C) water vapor dissociation. Such systems can result in overall energy efficiencies approaching 50%.

Determining the cost of producing this hydrogen is not a simple matter. This cost depends upon the cost of electricity (peak or offpeak), capital cost, and utilization factor. As a rule of thumb, hydrogen can be produced from natural gas for about $6-9/MMBtu. Electrolytic hydrogen can be produced for about $15-25/MMBtu. Due to the uncertainties in electricity cost, utilization factor, and capital costs, it is difficult to project future markets for hydrogen.

Hydrogen Storage - Current practice relies on compressed gas or liquefied hydrogen as the primary storage options. These storage systems do not lend themselves to bulk long-term or mobile short-term storage applications necessary if hydrogen is to assume an expanded role in the future U.S. energy infrastructure.

Substantial efforts in the U.S. and abroad toward advancing hydrogen storage technology have been only moderately successful. Various metal hydrides based typically on iron-titanium and magnesium alloys have been characterized and found wanting with regard to cost, weight/volume storage density, or required operating temperature/pressure regimes. Cryoadsorption of hydrogen in carbon at liquid nitrogen temperatures has been explored to some extent in Europe. DOE has supported R&D in advanced hydrides and in microcavities as hydrogen storage media.

Hydrogen Transport - Supplementation of natural gas with hydrogen is one option under consideration for future energy systems. Assuming efficient conversion of a given primary resource to hydrogen, some savings over electric energy transmission potentially could be realized if this energy were transported by pipeline. These are: reduced transmission losses limited to pressure drop and leakage compared to impedance losses, reduced capital cost of pipe compared to power transmission lines, reduced costs of right-of-way. To use this option, it is necessary to establish the compatibility of hydrogen with conventional pipeline steels. Protective measures for ensuring the safe and effective transport of hydrogen via available pipelines would require research.

HYDROGEN ACCOMPLISHMENTS AND FUTURE NEEDS

Accomplishments over the past decade derived from the hydrogen component of the C/HES program are summarized:

- Solid Polymer Electrolyte (SPE) Water Electrolysis System--General Electric - Comprehensive R&D program culminated in the fabrication and test of a 200-kW system which approached high efficiency and cost goals. Another smaller 20-kW unit demonstrated reliable on-site production of hydrogen which was used for utility electric generator cooling. Technology subsequently sold to Hamilton-Standard which is currently pursuing commercial prospects.

- Static Feed Water Electrolysis--Life Systems, Inc. - Multicell (1 ft) module designed, fabricated, and tested, demonstrates the ability to electrolyze brackish water and sea water. The system eliminates need for electrolyte circulating pump as well as water treatment subsystem, thus maximizing reliability and permitting low-cost manufacturing of molded parts. Technology was transferred to NASA-supported programs in Orbital Space Station Storage systems.

- Advanced Alkaline Water Electrolysis--Teledyne Energy Systems - Modest R&D program was able to demonstrate substantial improvements in electrolyzer elements (electrodes, catalysts, structural components). Limited success in separator development which would have permitted higher temperature (125-150C) operation.

- Underground Storage--IGT - Comprehensive engineering analyses show feasibility and problems of long-term storage in depleted wells and in caverns.

- Metal Hydride Storage - A wide range of alloys prepared and tested to show a safe alternative to compressed gas and liquefied hydrogen storage. Studies have shown, however, that low-cost, high-storage-density materials require high temperature for hydrogen release. On the other hand, low-temperature materials exhibit low storage densities and high cost.

- Rapid Cycling Applications (Metal Hydrides) - Chemical compressors in early states of commercialization. Metal hydride pair chemical heat pump proved viable for heating and cooling. Hydrogen separation/purification shown to be an alternative to pressure-swing adsorption and cryogenic separation.

- Hydrogen Transport/Transmission - Long-term program initiated by Sandia and completed by Battelle Laboratories fully characterized key problems of hydrogen embrittlement in pipeline steels. Battelle also demonstrated that additive gases (inhibitors) eliminate a number of the embrittlement problems.

- Hydrogen Technology Evaluation Center (HTEC) - Brookhaven National Laboratory facility was used to demonstrate the characteristics of interfacing an advanced technology electrolyzer with a photovoltaic system for hydrogen production, with coupling to electric grid. The facility was also used to conduct a performance mapping of a metal hydride compressor operating in both the closed and open loop modes. Test programs provided an opportunity for training/technology transfer involving representatives from MIT, Florida Solar Energy Center, EPRI, Public Service Electric and Gas Company of New Jersey, and the University of Hawaii.

Ongoing R&D activities are briefly described:

- A study examining the potential of hydrogen derived from renewable energy sources is continuing. In this effort, the status of current renewable hydrogen technology will be compared with conventional hydrogen production and areas where additional research might result in significant improvements will be identified. The ability of an energy infrastructure to assimilate greater hydrogen usage will be addressed, using Hawaii as the model. A major hydrogen application derives from benefits in increasing the hydrogen/carbon ratio of biomass to produce liquid fuels, e.g., methanol.

- A major program is being conducted by Westinghouse developing their thin film solid oxide technology for high-temperature water vapor electrolysis applications. Cell testing has shown performance in the 1.3 V range at current densities of 300 A/ft^2, and also conversion of up to 90% of steam to hydrogen and oxygen. A comprehensive theoretical model of vapor electrolysis is being developed which will provide information to improve performance.

- Several activities are underway investigating medium-temperature electrolysis in the 300-600 C temperature range. Brookhaven National Laboratory and Politecnico di Milano have recently completed characterization of aluminum phosphate and barium sulfate as "unsuccessful" candidate materials. In a parallel investigation the University of Pennsylvania has examined the use of beta alumina as a proton-conducting material suitable for medium-temperature electrolysis. Data have been obtained on thermal stability and conductivity as a function of water vapor pressure. Subsequent to a competitive procurement, Stanford University has identified a novel hydrogen ion conducting electrolyte which may provide a basis for a successful intermediate temperature range water vapor electrolysis system. Further, this electrolyte may serve to enhance prospects for using low cost hydrides as hydrogen storage media via the electrochemically - assisted dehydriding reaction.

- Battelle Columbus is addressing a novel approach to photolytic hydrogen production making use of plasma/polymer-coated semiconductor electrodes. Progress has been made in optimizing stability, optical transparency, and electrochemical cell characteristics.

- A key program in hydrogen storage is going on at Syracuse University attempting to make use of catalyzed, activated carbon to store hydrogen at low temperatures suitable for use in mobile/stationary applications. Adequate storage has been demonstrated on the macro scale but only at very low liquid nitrogen temperatures. Current work is investigating higher pressure, higher temperature operation, and alternate carbon materials. A class of super-activated carbons treated to provide high surface acidity has been found to satisfy 4% by weight system requirements at temperatures of 150 K (liquid freon temperatures).

Senator FORD. Thank you very much.

Mr. Reck, do you want to proceed with yours? Then we will have some questions.

STATEMENT OF GREGORY M. RECK, ACTING DIRECTOR, PROPULSION, POWER AND ENERGY DIVISION, OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. RECK. Thank you very much, Mr. Chairman.

I am pleased to be here this afternoon to discuss NASA's research activities associated with hydrogen utilization. I have a prepared statement which I would also like to submit for the record.

NASA is one of the largest users of hydrogen in the United States. We have learned to work with it. We use it in our launch operations and our test facilities. And we have recognized its attributes for a number of years.

Our experience base with hydrogen dates back to the 1950s when we first began studying the use of hydrogen, and our interest at that point was in high altitude reconnaissance aircraft. Hydrogen has very promising characteristics for that mission. It has excellent combustion characteristics, high volatility, wide range of flammability, low ignition energy, all of which make it very attractive in extending the range of jet engines to high altitudes.

To demonstrate that capability, the NASA Lewis Research Center conducted a series of flight tests of a B–57 aircraft in which one engine was modified to operate on hydrogen fuel. The liquid hydrogen fuel was carried on board. It was pressurized with gaseous helium, forced into the engine, passed through a heat exchanger on the way which converted it to a gas, which was then injected in the modified J–65 engine. A number of test flights were conducted. They were quite successful, demonstrated the feasibility of operating an aircraft on hydrogen fuel at high altitude although the modifications that we made to the aircraft really were not representative of the kind of changes that you would make in a commercial transport aircraft.

Following these tests, throughout the 1960s we focused most of our attention on space applications and looking at hydrogen for power systems and rocket systems for space propulsion. However, in the 1970s we again returned to the aircraft related issues, and from 1974 to 1980 we studied a number of issues that really needed to be addressed for consideration of hydrogen as an aircraft fuel for commercial subsonic jet aircraft.

The principal contractor for us in most of these activities was Lockheed California. And in most of the studies, we examined several alternate fuels, liquid hydrogen as well as liquid methane, and made comparisons with kerosene based commercial transport fuels, typically Jet-A.

Lockheed studied aircraft performance for several missions, short-haul missions as well as long-haul missions. In the short-haul missions, they looked at carrying 130 passengers up to 1500 nautical miles, and for the long-haul mission, we looked an aircraft to carry up to 400 passengers 5500 nautical miles. In the studies we tried to optimize the vehicle for the mission and the fuel combination. So, what we determined was the empty weight of the aircraft, the gross takeoff weight of the aircraft and the energy efficiency of the aircraft.

It turned out that for the missions that we examined in general the hydrogen-fueled aircraft showed a significant advantage over the Jet-A aircraft especially for the long-haul missions. And in fact, we found that with hydrogen fuel, the gross takeoff weight was on the order of 25 percent less than a similar aircraft that was carrying Jet-A fuel. The energy efficiency was on the order of 10 to 13 percent less, but that was strictly looking at the energy consumed on board the aircraft and did not take into account any energy efficiencies associated with the production of the hydrogen before it was loaded on board.

Lockheed also looked at the overall aircraft design, tried to identify the best location for the fuel tanks on the aircraft. And instead of wing tanks located in the wings as on current aircraft flying today subsonically, the preferred location that Lockheed identified was in the fuselage. And it would be in pressurized tanks located both forward and aft of the passenger compartment.

A number of other aspects of the on-board systems were studied. This included insulation techniques. They identified preferred insulations. Closed-cell foam appeared to be the most attractive. They looked at other features of the delivery system on board the aircraft. They identified problems in the pumps that might be used for the hydrogen fuel and also identified potential solutions. And in fact, some of the technology that we have identified associated with turbo pumps and bearings in the rocket research programs we have will likely pay off in identifying alternatives for some of the problems in the hydrogen pumps for aircraft.

Lockheed and Boeing also looked at airport logistics associated with trying to handle hydrogen fuels within the airport. They identified a concept that they felt would work at two major international airports which they studied.

In this concept hydrogen is brought into the airport as a gas through a pipeline. There is a liquefaction plant and storage facilities located inside the airport. And the hydrogen is distributed then from the storage facility to the aircraft via a closed-loop system that circulates liquid hydrogen. At the aircraft location a hydrant truck then transfers the liquid hydrogen to the aircraft, captures any boil-off gases, which typically can be up to 15 percent for a transfer operation, and returns these back to the liquefaction plant for recycling. So, none of the hydrogen would be lost in this process.

They also examined safety as part of these studies, and investigated some of the post-crash characteristics and hazards associated with hydrogen fuel. Hydrogen has a number of very positive aspects from the safety standpoint. It has a low flame emissivity. This means it radiates very little heat. It is not likely to combust the materials that are located nearby. It doesn't create smoke when it burns, and it is also very light and buoyant as a vapor. So, if a hydrogen spill occurs from the tanks, the hydrogen will vaporize quickly, and the hydrogen cloud is likely to float or move away from the area very rapidly. If the hydrogen cloud were ignited, we would expect the same behavior.

There are also negative aspects though associated with hydrogen. It is very volatile, so any spill is going to vaporize quickly, mix with air. And since hydrogen has such a wide flammability range, even very low concentrations are going to be combustible.

Also, if the hydrogen-air mixture is trapped or confined in any volumes, it has a potential hazard of detonation, which is a very explosive combustion process.

To address some of these concerns and to demonstrate some of the positive aspects associated with hydrogen, we conducted tests at the White Sands Test Facility where we spilled liquid hydrogen—1500 gallons—out on the ground and observed the diffusion and propagation of the hydrogen cloud that was generated. We conducted about a half dozen tests. In none of the tests the hydrogen cloud was ignited. But we did observe the buoyancy effect. The cloud moved up and moved away from the spill site. And we also observed an increased level of turbulence within the cloud over what we expected which tended to accelerate the mixing process so that the diffusion of hydrogen happened more rapidly than we expected, down to concentrations that would likely not be flammable.

We also looked at hydrogen production associated with the aircraft studies. Work was done by the Institute of Gas Technology and the LINI Division of Union Carbide. In these studies, again, we tried to compare liquid hydrogen and liquid methane, and in this case a synthetic jet fuel that would be produced from either coal liquids or shale oil. We looked at a number of processes. We looked at several feed stocks for the liquid hydrogen.

In general, the thermal efficiencies associated with producing the hydrogen were considerably less than producing the jet fuels, for example, from shale oil. And in fact, the predicted costs from the studies indicated that the cost of producing hydrogen would be at least twice or more from the coal liquids than it would be to produce more conventional jet fuel from these liquids.

I think that the results of most of these studies certainly indicate that it is feasible to operate subsonic aircraft on liquid hydrogen fuels but that the real investment in terms of research needs to be made in advance production technologies. It is certainly feasible aviation fuel, but the pacing item is cost at this point.

I would like to talk for just a couple of minutes about the aerospace plane. This, of course, is a joint Department of Defense and NASA activity. Our objective is to develop the technologies associated with hypersonic, very high speed flight in the atmosphere, and then acceleration of that vehicle to orbit. And for this system hydrogen plays a very crucial role. And in fact, it is enabling for orbital missions. Above Mach 5 to 7, above that range, hydrogen is essential for cooling parts of the aircraft and parts of the engine. And in fact, hydrogen also is necessary to sustain the supersonic combustion process that is very critical to the propulsion system for these aircraft.

We have research activities under way jointly, again, with the Defense Department agencies that are participating with us in the program looking at the propulsion system, the processes inside the systems on board the aircraft that support the engines. And we are also looking at lightweight hydrogen cooled structures and materials as a part of that study.

In the area of rocket propulsion, of course, we have extensive experience with hydrogen dating back into the 1950s. The ongoing research here is focused on durability and life issues associated with hydrogen systems and hydrogen rockets, as well as performance.

And at some point in the future we anticipate space-basing our transportation vehicles on hydrogen. In this concept, we would locate a hydrogen storage system in low earth orbit. We would use space-based, hydrogen-powered orbit transfer vehicles to carry payloads to higher altitude orbits, then return to the depot that would be in low earth orbit, and refuel.

We are conducting a ground-based program currently looking at the technologies associated with handling, storing and transferring liquid hydrogen in space. And we hope to fly a flight experiment to verify those technologies in the early 1990s.

In the space station program we intend to use hydrogen fuel to maintain the space station attitude and position. The hydrogen will fuel with the auxiliary propulsion system on board.

And certainly hydrogen fuel cells have been a part of our space power program for a number of years. They currently supply the power for the space shuttle. And we are examining regenerative fuel cells that would operate on water. During periods when there is excess power available, the excess power would be applied to the fuel cell. It would dissociate the hydrogen and oxygen. We would store the gases. And at other periods of time when there was higher level of demand than available power, we would recombine the gases in the fuel cell to generate the electricity. So, in this case it is an energy storage system.

In conclusion, I think we have in the past and will continue to use hydrogen when it is the correct fuel of choice. It will be used on the aerospace plane as the only fuel for orbital capability. It is very essential in space propulsion, and we are moving toward space-basing these systems. For aircraft our research has indicated that it is feasible to use hydrogen on aircraft. And we are confident that we can solve the remaining technical issues.

We are certainly interested and pleased that you are moving forward with research on hydrogen utilization. And we do believe that priority should be given to the issues that are associated with the production and manufacture and distribution and liquification of hydrogen.

This completes my statement. I'd be glad to take any questions.

[The prepared statement of Mr. Reck follows:]

STATEMENT

OF

Gregory M. Reck
Acting Director, Propulsion, Power and Energy Division
Office of Aeronautics and Space Technology

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

before the

Subcommittee on Energy Research and Development
Committee on Energy and Natural Resources
United States Senate

Mr. Chairman and Members of the Subcommittee,

I am pleased to appear before you today to discuss with you NASA's research activities in the area of hydrogen utilization. For many years now, this agency has recognized the potential benefits inherent in hydrogen use for aerospace propulsion and energy storage and has an ongoing research effort that began in the 1950's. I will describe the research that we have done in aeronautics, touch briefly on our current space applications using hydrogen and discuss the major issue which we believe is preventing its widespread use as an aircraft fuel.

In the mid-to-late 1950's, the National Advisory Committee for Aeronautics (NACA) investigated and successfully demonstrated liquid hydrogen as an aircraft fuel. This was accomplished by flying a B-57 with one engine modified to burn hydrogen fuel during cruise. The hydrogen system addition (Fig. 1) included a stainless steel wing-tip liquid hydrogen tank, a ram air heat exchanger to vaporize the liquid hydrogen, and a regulator to control the flow of fuel to the engine. The J-65 turbojet engine was modified by the addition of a hydrogen manifold and injection tubes. The aircraft utilized conventional military kerosene (JP-4) to power both engines for takeoff and climb to cruise altitude. One engine was then switched to hydrogen. Several flights were accomplished, with hydrogen operation occurring for approximately 20 minutes per flight.

With this as a base, from 1974 through 1980, NASA performed an assessment of the prospects for liquid hydrogen as a fuel for commercial subsonic jet aircraft. The program, whose funding averaged around one-half million dollars per year, addressed aircraft fuel containment, the performance potential, fuel-related subsystems, interface with airports, safety aspects, and fuel production efficiency and economics. It is generally recognized that liquid hydrogen is a clean-burning fuel which, because its energy content per mass is two and three-quarters times that of conventional jet fuel, is an attractive alternate fuel for aircraft. The NASA approach to the 1974-1980 studies was to consider liquid hydrogen as one of several candidate alternate fuels. Liquid methane and synthetic aviation kerosene were also considered as alternative fuels for various studies within that timeframe.

Studies conducted for NASA by the Lockheed California Company indicated (Fig. 2) that the best place to house the cryogenic hydrogen and methane was within insulated tanks located both fore and aft of the passenger compartment. It was found to be impractical to house the hydrogen or methane within the aircraft wing as is the current practice with kerosene fuels. This is because the volumes available are insufficient and tend to have a large ratio of surface area to storage volume, making insulation difficult. Wing-mounted tanks were considered but the drag penalties associated with such tanks were excessive.

The next figure (Fig. 3) shows some salient characteristics of hydrogen and methane-fueled aircraft compared to aircraft fueled with Jet-A, the commercial aviation kerosene. Two aircraft are considered, one designed to carry 130 passengers 1500 nautical miles and one designed to carry 400 passengers 5500 nautical miles. Their operating empty weights, gross weights, and onboard energy consumption per seat nautical mile have been referenced to those of Jet-A fueled aircraft designed to do the same job. Noteworthy advantages occur only for the 400 passenger, 5500 nautical mile range hydrogen-fueled aircraft, whose gross weight is 75 percent and whose onboard energy consumption (BTU per seat n.mi.) is 87 percent of its Jet-A counterpart. It is important to note that in this chart the BTU per seat nautical mile includes only the heating value of the fuel used in the mission and does not include the energy required to produce the particular fuels.

Fuel system definition studies were conducted by the Lockheed California Company aided by appropriate subcontractors. These studies addressed the systems and subsystems required to house the fuel on board the aircraft and deliver it to the engines. A variety of cryogenic insulation schemes were evaluated for application to both hydrogen and methane fuel tanks. Two-layer external closed-cell foam insulation and a microsphere system were found to be the two most attractive candidates. Concepts for pumps, lines, and purge systems were identified. Trade-off studies were conducted to evaluate the various concepts from the standpoint of cost, fuel consumption, reliability, maintainability, and safety.

A number of subsystem studies were conducted to give depth to the fuel system analyses. For instance, 2219 aluminum was selected as the preferred construction material for the liquid hydrogen tanks. A data search was conducted by General Dynamics to determine whether sufficient data were available to assure the successful long life operation of such a tank. Data gaps were identified, supplemental tests were conducted, and recommendations were made regarding additional testing.

Both experimental and analytical studies were conducted by Bell Aerospace and the A.D. Little Company to gain insight into the more promising closed-cell foam insulation systems for liquid hydrogen tanks. Dual layers of foam, each of which was covered by a mylar-aluminum vapor barrier, was found to be the more promising concept.

Conventional hydrocarbon lubricants cannot be used in the bearings of liquid hydrogen fuel pumps because of the extremely low temperature. Liquid hydrogen is used instead but because of its very low viscosity, making it a poor lubricant, pump bearings were thought to be a potential problem. One possible solution to long life, reliable bearings is the compliant foil bearing, a concept currently utilized in the environmental control system of commercial aircraft. Another is the hybrid bearing being developed at the Lewis Research Center under the Office of Aeronautics and Space Technology (OAST) space technology program.

Airport accommodations required to provide service of hydrogen-fueled aircraft were investigated in dual studies by Boeing and Lockheed. Both studies concluded that for major airports such as Chicago O'Hare and San Francisco International, the preferred concept would include (Fig. 4) pipelining hydrogen gas to the airport, construction of a hydrogen liquefaction plant and storage facilities at the airport, and the construction of a closed-loop liquid hydrogen circulation system delivering the hydrogen to hydrants. The hydrogen vapors produced during refueling of the aircraft would be returned to the hydrogen liquefaction plant for reliquefaction and then sent to the storage tanks. The preferred concept for aircraft fueling (Fig. 5) is that of a hydrant truck which connects the hydrant to the aircraft via helium purged lines. A second line captures boiloff gases. These studies showed that there were no technical problems associated with such airport facilities which did not lend themselves to rather straightforward engineering solutions.

Safety was also considered. Lockheed California and the A.D. Little Company assessed the relative post-crash fire safety of hydrogen, methane, and synthetic Jet-A fuel and identified key technical issues. Potentially positive safety aspects of hydrogen include: (1) its low flame emissivity; (2) the lack of smoke in a hydrogen fire which may aid passenger egress to safety; and (3) the buoyancy of hydrogen and its fireball that may reduce the damage from an engulfing flame. Potentially negative safety aspects include: (1) its high volatility; (2) its wide flammability limits; (3) its low ignition energy requirements; and (4) the potential for detonation of a confined or partially confined hydrogen-air mixture if ignited.

The behavior of flammable clouds resulting from large scale spills of liquid hydrogen was investigated by NASA and Ergo-Tech. In 1980, a series of 1,500-gallon liquid hydrogen spill experiments were conducted at NASA's White Sands Test Facility. Those efforts determined that dispersion of vapor clouds formed by rapid spills is accelerated to nonflammable concentration by turbulence generated from the evaporation and large temperature gradients. It was also observed that the cloud remained positively buoyant during this process.

Fuel production became an important part of the NASA investigations. Efforts conducted by the Institute of Gas Technology and the Linde Division of Union Carbide assessed the cost and thermal efficiency of producing liquid hydrogen, methane, and synthetic Jet-A fuel. The studies assumed that all three fuels would be produced from one of the U.S.'s most plentiful energy resources, coal. Later work included results of similar studies conducted for and by Boeing, which included synthetic Jet-A produced from oil shale. The studies showed that the thermal efficiencies of liquid hydrogen production processes were generally less than those for producing liquid methane or synthetic Jet-A. The relative cost of the various fuels delivered to the aircraft are shown (Fig. 6). The particular fuel production processes are identified as are the energy source. The chart is broken down into basic fuel production, pipelining the product 500 miles, and liquefaction, storage, and distribution at the airport. Also reflected are current and advanced liquefaction technologies and the sale of a heavy water by-product. These study results, done in 1979, are shown in 1980 dollars and are based on $16 per ton coal and electric power costing 3 cents per kilowatt hour. The results indicate that liquid hydrogen should cost roughly twice as much as synthetic Jet-A from either oil shale or coal. It should be noted that the purpose of the study was not to provide the definitive work on the subject but to guide our technology development effort. A more in-depth investigation of potential production technology improvements and their economic impact by the appropriate parties is recommended.

The feasibility of using liquid hydrogen as an aviation fuel was demonstrated in the late-1950's and these additional studies support its utilization. The pacing item regarding hydrogen appears to be the cost of fuel production relative to other available choices. The aircraft-related technologies have been put in abeyance by NASA until such time as there is evidence that fuel production economics have changed sufficiently to warrant a resurgence of those activities.

Any current discussion of hydrogen utilization would not be complete without mention of the National Aero-Space Plane program. In this program, which is being jointly conducted by NASA and DOD, hydrogen plays such a key role that here its use is enabling. It is clearly the fuel of choice at Mach numbers above seven because of its flammability characteristics, its energy content, and its heat capacity and heat transfer characteristics. Hydrogen-related research is being conducted in the areas of propulsion and structures. As part of the planned program, the hydrogen-fueled engine systems will be matured to full-scale, flight-weight devices capable of effective operation over the entire Mach number range of 0 to 25 required to reach orbit. The high stagnation temperatures expected during flight will require active cooling. Thus, research is being conducted which will provide an integrated structure, cooling system and fuel storage system. Unlike the earlier discussion of use in the subsonic regime, performance, not economic trades, is the key issue here.

Hydrogen is an important fuel for rocket propulsion and considerable research is being conducted in support of this application. Fundamental experimental data is being obtained from a Space Shuttle Main Engine, in a testbed facility, to better understand and define internal engine environments and to verify design methodology needed for the next-generation reusable earth-to-orbit engines. A technical foundation is also being developed for a very high performance hydrogen-fueled propulsion system designed for use in a space-based orbital transfer vehicle, an essential future addition to our space transportation system which is needed to extend space operations from low-earth-orbit to geosynchronous orbit and beyond. To support refueling operation in space, an experimental program is underway to learn how to handle and transfer liquid hydrogen in space. The first flight of the Cryogenic Fluid Management Facility Experiments is currently scheduled for 1994. Smaller hydrogen-oxygen auxiliary propulsion thrusters are being developed because of their high performance, clean plumes, and for Space Station availability of propellants.

In the area of space power technology, hydrogen is being used in the study of hydrogen-oxygen regenerative fuel cells for potential surface power application which may be required for future space missions. In addition to a projected weight advantage, the regenerative fuel cell possesses a significant advantage relative to battery storage systems in its flexibility to increase capacity by increasing the size of the storage tanks.

In summary, NASA has and will continue to use hydrogen when it is the correct fuel choice. It will be used extensively in hypersonic flight research and is the only fuel for an aerospace plane with orbital capability. It is an essential part of NASA's space propulsion program and new technologies are being developed which will extend its application in both space propulsion and space power. For commercial aircraft application, however, the picture is not so bright. As a result of our research, we feel confident that we can solve the few remaining technical issues. But the economic aspects of manufacture, liquefaction, storage, and handling are the key issues and they must be addressed if hydrogen-fueled air transportation is to be considered for use in the future. As progress is made toward resolution of the economic issues by the appropriate parties, NASA will address the remaining technical issues for hydrogen-fueled commercial aircraft.

HYDROGEN SYSTEM FOR B-57 AIRPLANE

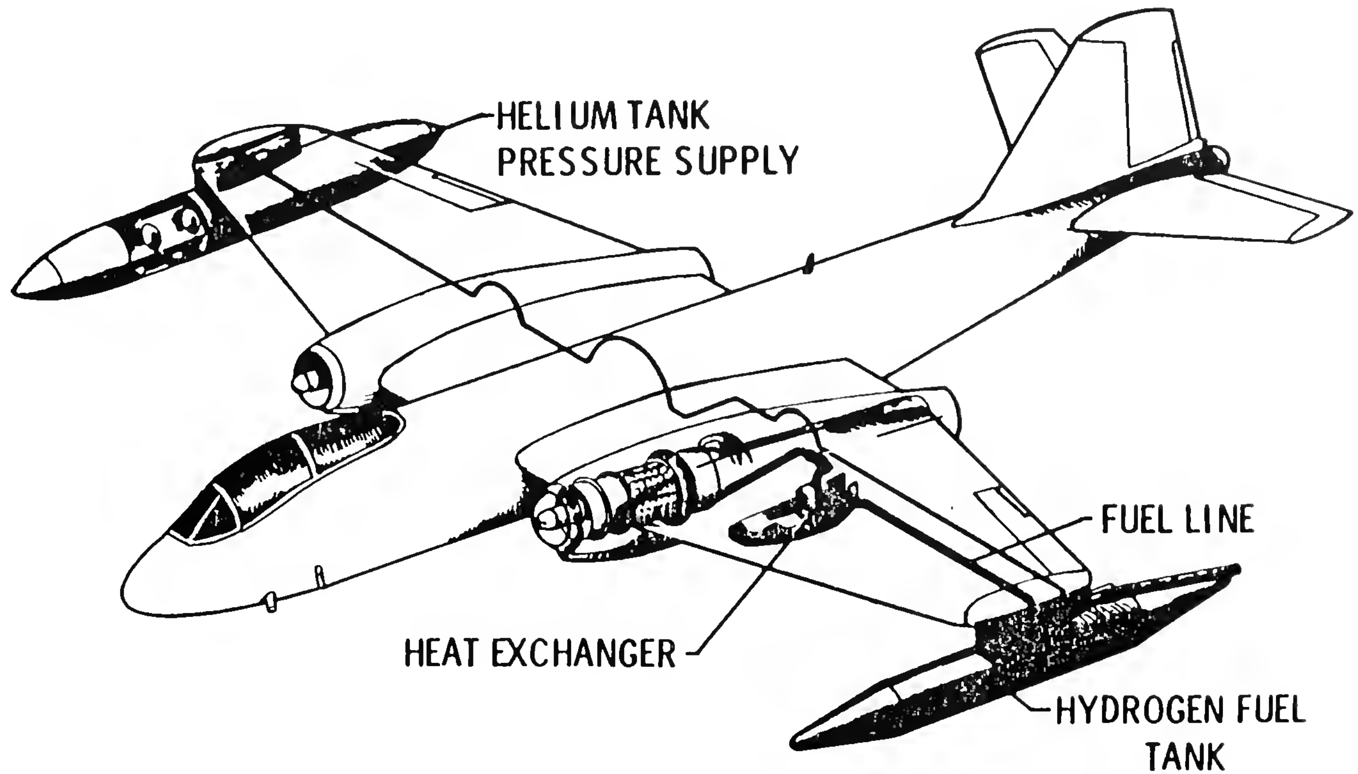
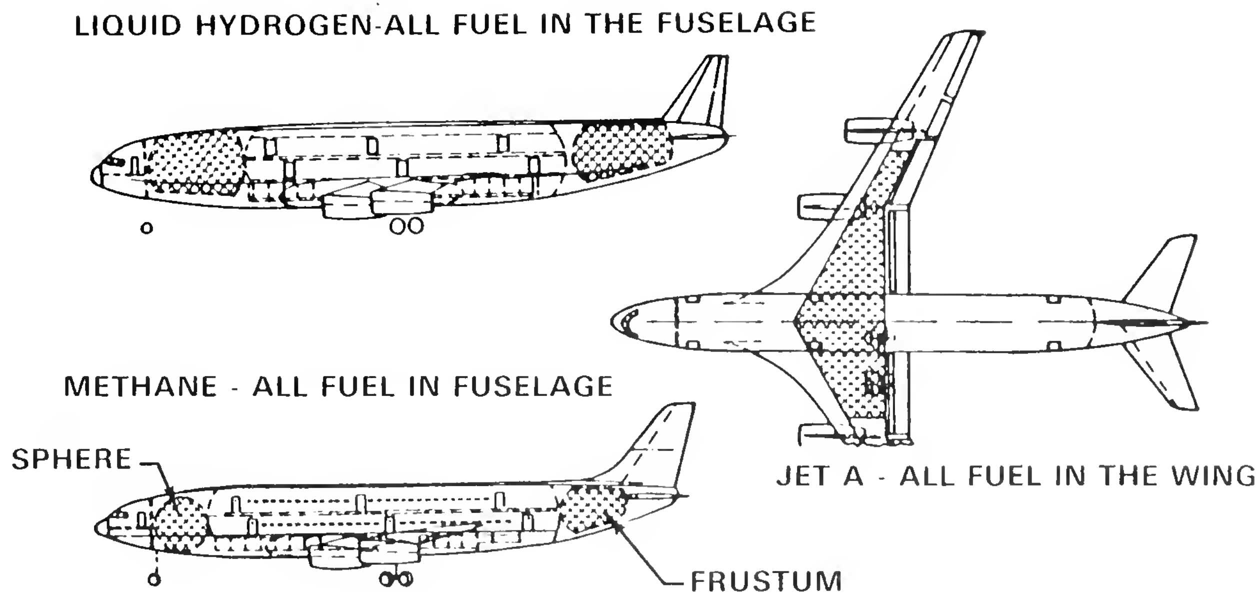


Figure 1.

FUEL CONTAINMENT FOR HYDROGEN, METHANE & JET - A AIRCRAFT



400 PASSENGERS
5500 N.M.
0.85 MACH

Figure 2.

SUMMARY OF HYDROGEN AND METHANE-FUELED AIRCRAFT CHARACTERISTICS, RELATIVE TO JET A

	130 PASSENGERS 1500 N.M.	400 PASSENGERS 5500 N.M.
DRY WEIGHT		
JET A	1.00	1.00
LCH_4	1.10	1.10
LH_2	1.08	1.00
GROSS WEIGHT		
JET A	1.00	1.00
LCH_4	1.03	0.99
LH_2	0.94	0.75
BTU/SEAT N.M.		
JET A	1.00	1.00
LCH_4	0.97	0.99
LH_2	0.98	0.87

Figure 3.

HYDROGEN LIQUEFACTION, STORAGE, AND DISTRIBUTION SYSTEM AT AIRPORT

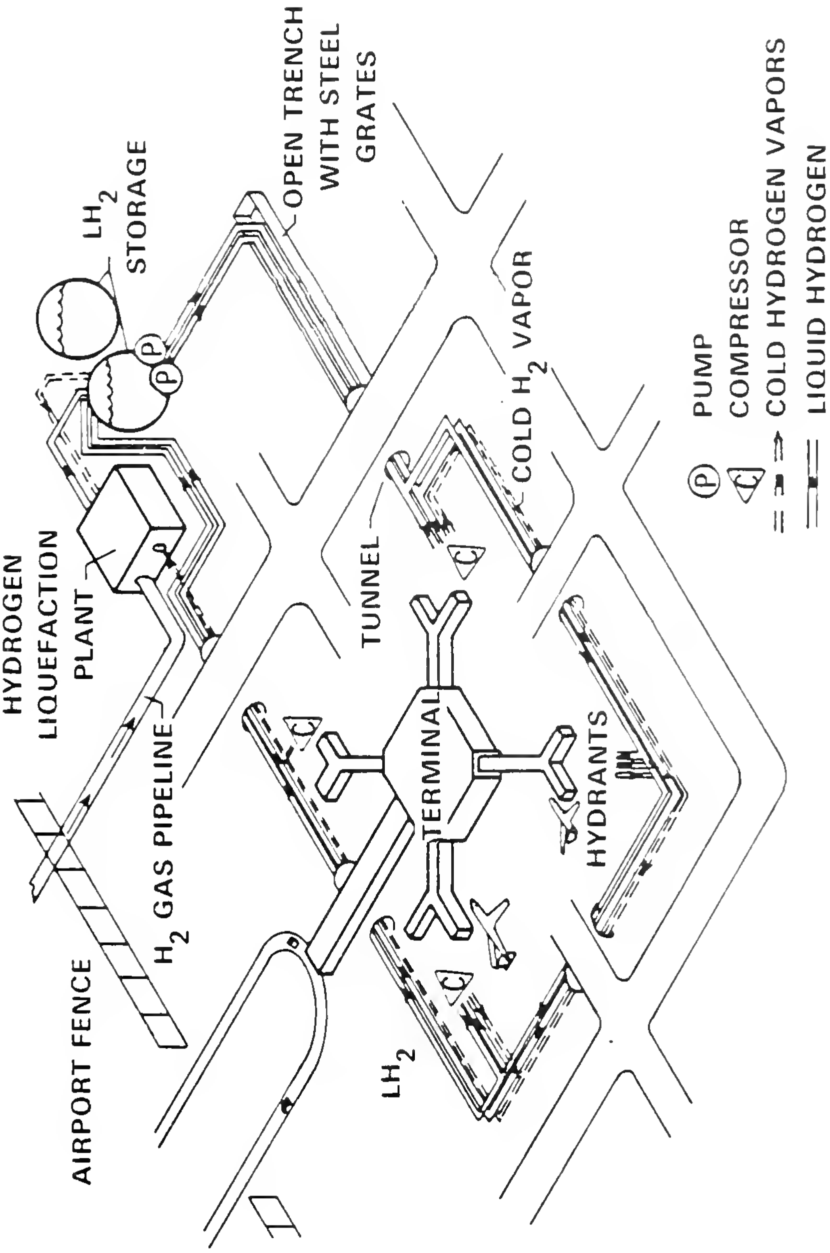


Figure 4.

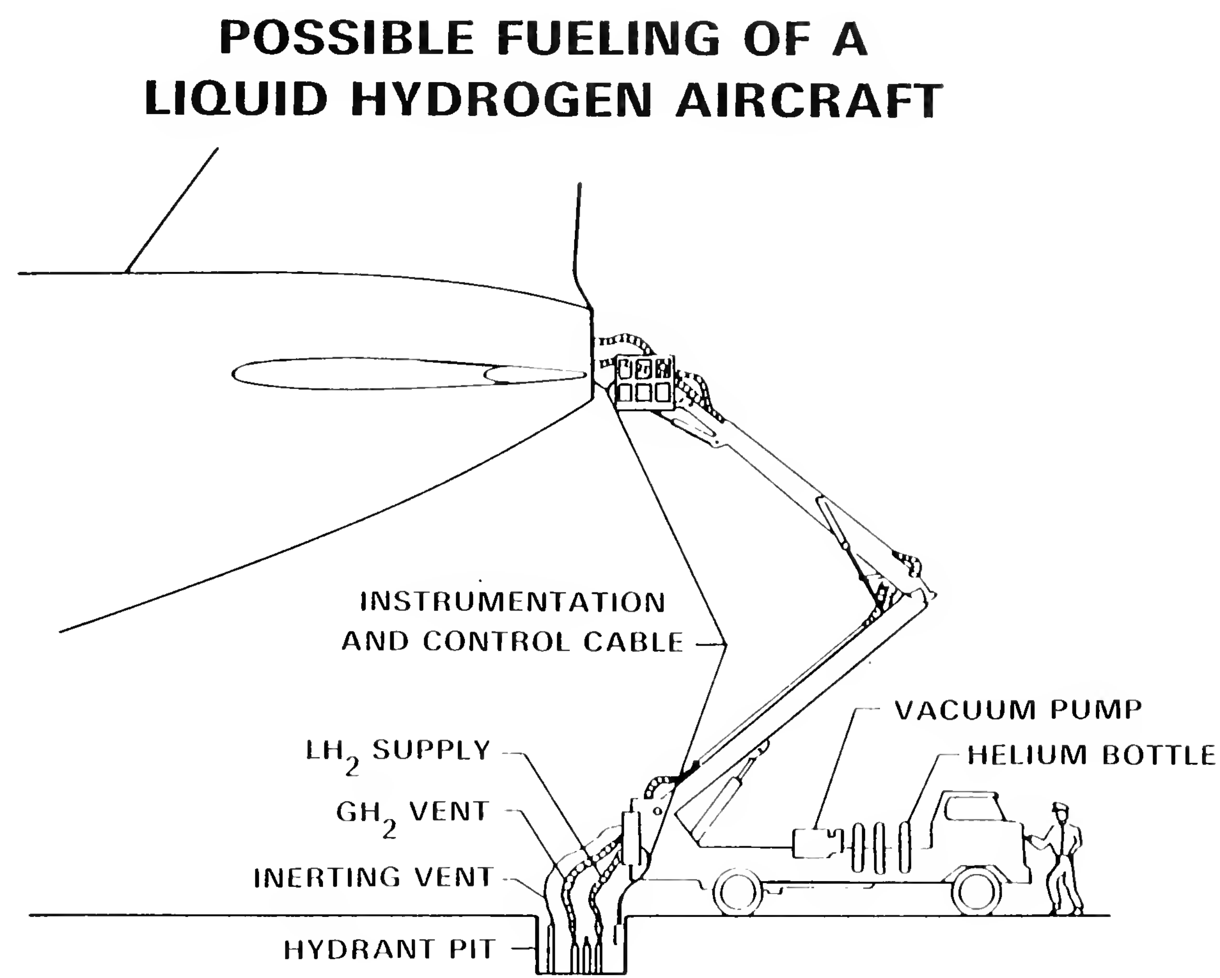

POSSIBLE FUELING OF A
LIQUID HYDROGEN AIRCRAFT
INSTRUMENTATION
AND CONTROL CABLE
VACUUM PUMP
HELIUM BOTTLE
LH_2 SUPPLY
GH_2 VENT
INERTING VENT
HYDRANT PIT

Figure 5.

ALTERNATIVE AND SYNTHETIC FUEL PRICES

DELIVERED TO AIRCRAFT

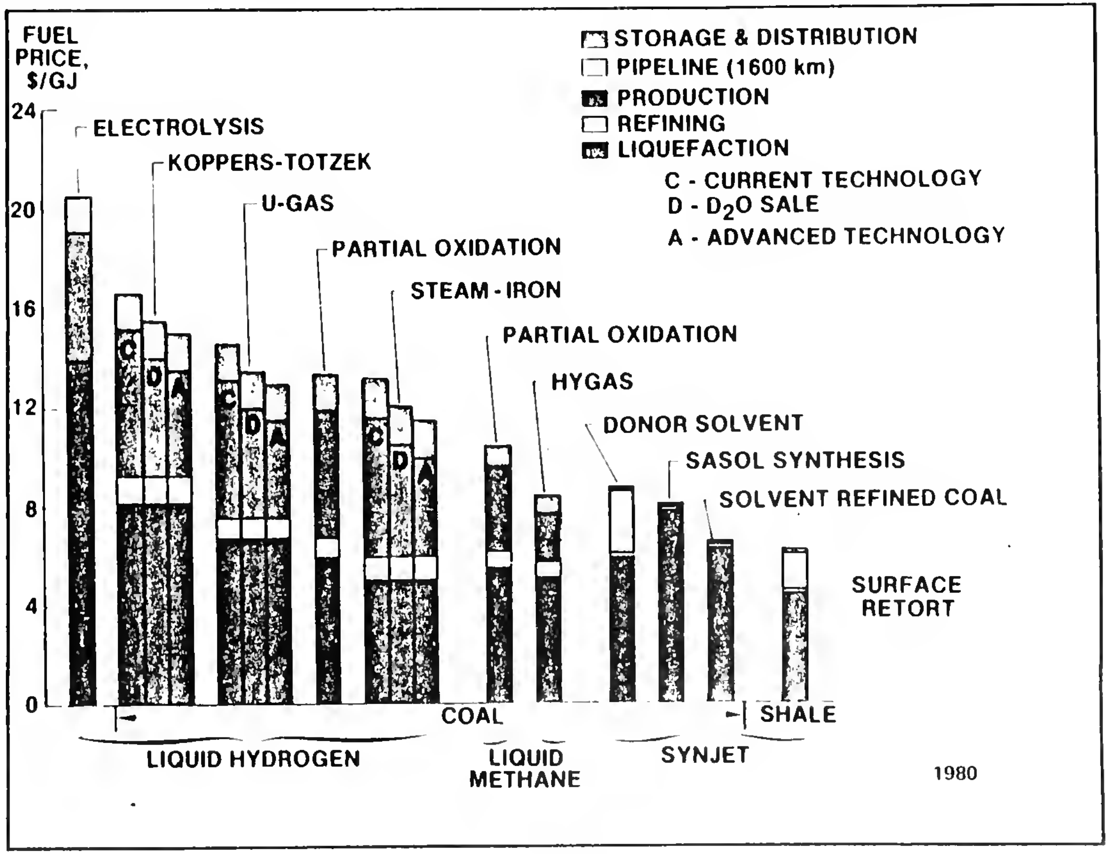


Figure 6.

Senator FORD. Thank you, Mr. Reck.

Madam Secretary, let me ask you a few questions, and then I will ask Mr. Reck, and kind of keep it in DOE and NASA.

Madam Secretary, you talk of hydrogen as a—and I quote from your statement—"secondary energy form." Does the use of renewables make hydrogen use more attractive?

Miss FITZPATRICK. Mr. Chairman, if we could find an abundant and fairly low-cost energy source to drive the production of hydrogen, then it would certainly be more attractive. And that, in fact, is the purpose of part of our research program. We are looking to hydrogen produced from renewable materials, such as biomass, plant material, and also we are studying how the process itself could be powered by solar energy, either directly or thermally through solar heat or through photovoltaics.

Senator FORD. Your main objection then is the cost of energy to produce the hydrogen. Did you say four times?

Miss FITZPATRICK. Four to fifteen times——

Senator FORD. Four to fifteen times.

Miss FITZPATRICK [continuing]. The energy must be invested in the process versus the energy you get out——

Senator FORD. One unit out of it.

Miss FITZPATRICK. Right.

Senator FORD. Your testimony promotes "continued research to improve the technology base of renewal energy conversion of system." Is this consistent with research advocated both in 1294 and 1296?

Miss FITZPATRICK. I think generally it would be, Mr. Chairman. The purposes of the Department's ongoing program, and I think the overall purposes of the legislation, as I understand it, are roughly consistent.

Senator FORD. Let me read a little bit then from your statement and ask you a fairly telling question. In your testimony you state that there are no activities at DOE which are related to the third purpose of S. 1294 "determining the technical requirements for employing fuel cells for power production as backup spinning reserve components to renewable power systems in rural and isolated areas."

And further you state this is a "low priority" because of the immaturity of the technology.

Later in your testimony you state "current programs are adequately funding to address the intent of these bills."

If the purposes of the bill, particularly S. 1294, are adequately addressed, why are there no activities in the Department for the third purpose just outlined?

Miss FITZPATRICK. I think the third purpose is a specific use of hydrogen or of fuel cells which is not among the major uses that we might look for in the uses of hydrogen as a fuel and of fuel cells as a power source. The program generally addresses the first two uses which are to produce hydrogen from renewable energy sources or using solar energy, which is the much broader, I think, primary purpose. So, number three is a particular application of the technology.

Senator FORD. Let me ask you this then in closing. Wouldn't S. 1294 help bring the state of the technology to maturity and to productive use?

Miss FITZPATRICK. Well, I think certainly if we can bring the technologies to maturity and have economical and energy efficient hydrogen production and fuel cells to use the hydrogen, then rural applications would certainly be one of the possibilities and backups to spinning reserves might be another. But all of that would have to be driven by what the available alternatives are and what the economic factors are.

Senator FORD. Mr. Reck, you discussed the pacing item for hydrogen, the cost of fuel production. What can the Federal Government do to accelerate research on hydrogen production and bring down the cost of that production?

Mr. RECK. I suspect that some of the research activities suggested by the bill would be very worthwhile.

From the perspective of NASA, we have not been directly involved with hydrogen production to any extent other than through the studies that I've described that our contractors have pursued. As part of that study, they did not get into any of the production technologies that they felt should be addressed and exactly the details of what should be done there, simply that they felt that trying to improve the efficiency of the liquefaction process, which takes up a considerable portion of the energy that is used in producing liquid hydrogen, would be one area that could be tackled. And they did not specifically identify any of the areas associated with producing the hydrogen itself.

So, I guess I am not really in a position to answer which technology should be dealt with there. But we certainly feel that it is critical to try to tackle the cost issue.

I suspect the one thing that we are trying to support with some small funding in the agency is trying to improve the efficiency of transport. The transfer that I mentioned, the storage are issues that in the end tend to raise the overall cost of hydrogen. It is very difficult to store liquid hydrogen for a very long period of time without any losses. And when transfers are made from one vessel to another, you can lose 15 to 25 percent of the liquid hydrogen in the process. And that is very expensive, and it costs us a great deal to make those transfers. Anything that we could do to improve that efficiency would help.

Senator FORD. What role do you see for renewables, solar, wind, biomass, in hydrogen production?

Mr. RECK. As I understand the technology, those would be sources of energy that would be used I think most effectively in supplying power to fuel cell systems to generate hydrogen and transport that hydrogen to other user sectors.

We have been involved with the Department of Energy in joint activities developing those renewable technologies, wind energy, photovoltaics, and so forth. And I think we have participated in demonstration projects along those lines. So, we have offered the technology and the capability that we have within NASA to participate in those programs.

Senator FORD. S. 1296 establishes the Hydrogen Fuel Aircraft Advisory Committee. What do you think about the potential effectiveness of such a committee?

Mr. RECK. We have within the agency now a system of advisory committees that we use in helping us direct and guide the research activities that we conduct both in space and aeronautics. Those committees have been very effective in helping us identify new technologies that should be incorporated. We try to draw from the various sectors and cover a number of the sectors that are identified in the bill, including private industry, the academic community. We use these groups, as I say, to review the ongoing activities that we have and to help guide us in terms of what we should be doing. And they also provide a very effective means of transferring the technology that we generate out to those communities, helping us advise on the best means of doing that.

I feel the system that we have now works very effectively, and we are working with people within the aviation industry that understand the economic issues, understand the market issues and so forth associated with that. I think it would be very important to be sure that any panel that were established under the auspices of the legislation would also serve those purposes to be sure there are individuals who are familiar with the organization.

I would also submit that perhaps the advisory groups that we already have established within the agency might be able to satisfy the same purposes.

Senator FORD. As long as you are doing it, it is fine. And when you fail to do it, there ought to be some carrot or stick there I think. So, maybe we might try to accommodate each other as it relates to that particular phase.

What is your comment on the $100 million funding that is provided for hydrogen-fueled aircraft research?

Mr. RECK. I think it certainly would be valuable in terms of developing the technology at a fairly small scale level. Any large scale demonstration program, as suggested in the legislation, I think would require funding that would be substantially in excess of that.

For example, the first program that we have experience with now in terms of a hydrogen-fueled vehicle is the aerospace plane. Now, the technologies there are much more sophisticated in many cases than what would be required. The research and technology program, the three year research and technology program, for that activity is approaching $700 million. And we anticipate the first several vehicles for research flight test purposes will require about $3 billion.

Senator FORD. That's $3 billion?

Mr. RECK. Yes, $3 billion. That is the run-out budget for phase three which would carry it through the flight test program. At least a good part of that is associated with the hydrogen—supporting the hydrogen on the aircraft. Another part of that, obviously, is developing the technologies for the high speed flight.

But I feel that the levels of resources suggested here at best would conduct smaller scale, perhaps ground test programs or flight demonstrations in which only portions of the aircraft systems might be modified to operate on hydrogen. I am not sure exactly how valuable a demonstration like that would be if it wasn't directed at a mission and didn't have the ability to redesign the aircraft to take advantage of all the benefits that are associated with liquid hydrogen. The aircraft designs that Lockheed generated as part of our studies in the 1970s merely started with a clean sheet of paper.

By locating the fuel inside the fuselage, for example, rather than the wings, they changed the load distribution on the air frame. There are economies associated with that. There are economies associated with the engines, for example, in using the heat sink available in the hydrogen to help reduce the temperature of the turbine cooling air which can improve the efficiency of the engines.

I think some of those could be studied on the ground, and we certainly, prior to the B-57 test that I described, ran an extensive wind tunnel test program of the complete system.

So, those are the kind of things that probably could be done with the level of funding that would be available as currently proposed in the legislation. It would be difficult I think to conduct a meaningful large scale demonstration with these resources.

Senator FORD. I have no further questions.

Senator Matsunaga, do you have any questions?

Senator MATSUNAGA. Yes. Thank you, Mr. Chairman.

Now, Secretary Fitzpatrick, the White House issued a White Paper in February of this year entitled "National Aeronautical R&D Goals," which says in part, "The dearth of foreign aeronautical resolve and the concerted national effort required to preserve American competitiveness are still largely underestimated. Sustained U.S. leadership will require greater achievement by all sectors, government, industry and academia. Both the opportunity and challenge are unprecedented."

Now, if this is the administration view—and I certainly share it—why aren't you, as the ranking administration spokesman here this afternoon, more enthusiastic about the hydrogen bills? They certainly will permit greater achievement in aeronautical resolve on the part of all three sectors, would they not?

Miss FITZPATRICK. Senator, I certainly am not going to gainsay the Administration White Paper. But I don't think that I am the person to talk to about aeronautical goals. Certainly Dr. Reck is fully qualified to do that.

Our job at the Department is to study hydrogen as an energy source. One of the energy applications would be in aeronautics. And we are certainly working very hard and closely with NASA and with DARPA on what the requirements will be for the aerospace plane. We have had meetings with them, and we are working on a joint research plan. So, we are fully prepared to do our part to see that those goals are achieved.

Senator MATSUNAGA. Are you satisfied that with your present resources and organizational structure with regard to hydrogen you can meet the White House challenge?

Miss FRITZPATRICK. Well, that was the purpose of having some meetings. Some of them have gone on very recently within the last month. And if the experts coming out of those discussions want to recommend further changes in our research program, then I am certainly prepared to listen to them.

Senator MATSUNAGA. Well, one of the objections you raised, if you can call it an objection, to the three bills in your testimony which you presented is that the hydrogen will become feasible only when its production costs come down. Now, isn't the bringing down of the production costs one of the objectives of any research and development program?

Miss FRITZPATRICK. Certainly. It is a primary objective of our program.

Senator MATSUNAGA. So, you are not then opposed to any project which would go into that aspect of alternative energy development, namely, hydrogen.

Miss FRITZPATRICK. If that project fits within a rational framework of approaching all of the problems with hydrogen, cost being one of them, certainly we support those, and that is what our current research program attempts to do.

Senator MATSUNAGA. Well, in your testimony you also mention the fact that hydrogen is not a primary energy source and must be manufactured. And of course, the Chairman raised this question also. But isn't it true that principal fuels, such as petroleum for example, also take other forms of energy in order to be produced in the first instance?

Miss FITZPATRICK. Certainly. The petroleum comes out crude, and we refine it—that's true—into separate fractions.

Senator MATSUNAGA. So that if we can find through research some cheaper means of producing hydrogen, wouldn't that be taking advantage of a vast natural resource in which initially we had assumed the world leadership, and we seem to be falling behind?

Miss FITZPATRICK. That's true. If we can find an economically and energetically efficient means of producing, storing, transporting and using hydrogen, it is certainly a worthwhile goal, which is why we do have a research program in that area.

Senator MATSUNAGA. Well, I do hope then that your Department will fall in line and push these energy programs and help to get these bills passed so that we can work together and assume the common objectives.

Miss FITZPATRICK. Well, we certainly have common objectives, Senator, yes.

Senator MATSUNAGA. Of course, Mr. Gregory Peck—I mean, Mr. Reck—I take it from your testimony that——

Senator FORD. Gregory is on TV against Mr. Bork. Be careful. [Laughter.]

Senator MATSUNAGA. I take it, Mr. Reck, that NASA is somewhat more enthusiastic about the hydrogen bills, which are the subject of these hearings, than the Department of Energy is, and I thank you for that. Of course, perhaps the application of the form of energy is much more in line with NASA's programs.

But I was very much interested in learning of your work with Lockheed because, as you probably know, Lockheed had intended to build a 1,000 megawatt OTEC plant, the ocean thermal energy conversion plant, in Hawaii on the big island for the purpose of producing liquid hydrogen. And it had been estimated that it would take about 400 megawatts to produce all the transportation fuel needs of the State, both ground and air, and 600 megawatts additional being produced by the OTEC plant planned would produce enough to produce liquid hydrogen for export. And this would have been a great thing for Hawaii. Unfortunately, because of the position taken by the present administration, Lockheed decided to drop the project. As a matter of fact, if you come to my office, I will show you a big photograph of the prototype, LH–2, the plane, a liquid hydrogen plane, which Lockheed on the planning board.

And I do hope that with the passage of this bill, you will work with Lockheed or any other plane manufacturing firm to develop hydrogen-fueled aircrafts.

Thank you very much.

Mr. Reck. Thank you, Senator.

Senator Ford. Thank you. We appreciate your testimony today. There may be some questions that will be submitted to you in writing by other members of the subcommittee. I hope that you will accept those and reply in a timely fashion. Thank you both very much.

The next panel is the President of Industrial Fuel Cell Association, Frank W. Spillers; the Director of External Relations, Northeast Utilities Company, Fuel Cell Users Group for the Electric Utility Industry, Mr. Eugene Sturgeon.

Mr. Spillers, since I called you first, I'd allow you to go first. And we will accept your testimony in full. If you want to highlight it, it would be fine.

Mr. Spillers. Okay, thank you, Mr. Chairman.

Senator Ford. We never know when we might have a roll call, and so we may have to jump and run. Hopefully we can get through this hearing this afternoon without too much disruption.

STATEMENT OF FRANK W. SPILLERS, PRESIDENT, INDUSTRIAL FUEL CELL ASSOCIATION

Mr. Spillers. I think it will just take a few minutes.

My name is Frank Spillers. I am President of the Industrial Fuel Cell Association. I am a 27 year employee of Dow Chemical where I am presently Director of Discovery Development for our Texas research organization. My interest and involvement in electrochemistry, including fuel cells, dates back to 1973.

Our organization, the Industrial Fuel Cell Association, is a not-for-profit organization. It is composed of members from the oil industry, chemical manufacturers, auto industry, minerals, utilities, auto industry and other potential users of fuel cells. Other members are corporations involved in the development and potentially the manufacture of fuel cells and fuel cell components.

We are very pleased to have the opportunity to testify before you today on Senate Bills 1294, 1295 and 1296. We wholeheartedly support the general thrust of these bills, but we do have some areas of concern which I will address later.

Taking a broad view, we believe you are on the right track in trying to encourage alternate energy technology for the future of our country. This is great and should be applauded by all citizens. Unfortunately, I think you may have to wait a while for the applause. Right now we receive electricity at the flip of a switch, and we don't wait in line, as we did during the 1973 oil embargo, to fuel our automobiles. Our general population probably won't get concerned until the lights go out and the pumps go by.

But as Llewellyn King, publisher of The Energy Daily, recently told a gathering of the Southern Governors Association, the United States can no longer be complacent about our future fuel supplies. Further, King said we better start worrying again that there will be insoluble problems within a decade and perhaps problems with electricity supply before then.

Expanding on Mr. King's electrical supply concern, it is well known that there are not any new central power stations on the drawing board today. It is also generally accepted that there will be power shortages starting in the mid-1990s.

Fuel cells, which of course require hydrogen for fuel, may be called on to fill the gap. They appear to be well-suited for the task due to modular construction which gives you short delivery lead time and the ability to be fitted to dispersed sites.

Our country has many problems to face here at home and abroad, but I believe the safety of our future energy base should be near the top of this list. As recently pointed out in the Congressional Record, the U.S. has only enough proven petroleum reserves to last nine years if the circumstance ever arises. With world tension as it is, one must wonder not if circumstances arise, but when.

Again, we support the general thrust of the proposed legislation to lead the way in developing a secure domestic source of alternate energy. Our association stands ready to assist in any way we can.

With your indulgence, I would now like to make some comments and address some concerns on the legislation under consideration today.

Senate Bill 1294 is welcomed by our association. It addresses the opportunity of producing hydrogen from renewable energy sources and using this hydrogen in fuel cells to produce electricity. The energy sources named in this bill will be available to our country forever, and we need to learn to use them for efficiently. The only concern we have is that this bill calls for only one year of funding. We believe it will probably need to run for a longer term.

Going on to Senate Bill 1295, we believe this bill is needed, and we support it almost as written. We welcome the call for the EPA to prepare Federal environmental and safety guidelines for cities' and municipalities' use of fuel cell technology.

In addition, we would suggest that the Industrial Fuel Cell Association could take an active role in helping to prepare these guidelines. Later we would be pleased to offer our Association's help preparing fuel cell performance and manufacturing standards. The setting of guidelines and standards is one of many points that needs to be addressed, and there is no need for delay.

This bill also calls for the Secretary of Commerce to assess the export market potential for fuel cell systems with renewable technologies. We welcome the probable confirmation of the market by the Secretary.

We also support the inclusion of fuel cells as a fuel conservation technology under REIDA, as called for in this bill.

The section of Senate Bill 1296 calling for research and development on hydrogen-fueled aircraft is a step in the right direction of addressing our fuel needs for transportation.

In addition, we would suggest a similar approach to our land-based transportation. DOE/EIA report 0214 shows the 1985 U.S. motor vehicle consumption was nearly 3 billion barrels. A national energy use of this magnitude would be a very worthwhile target for fuel cell use.

Most people who have pondered the question of fuel cell automobiles have concluded that the hydrogen fuel would best be arrived at by reforming methanol. Methanol can be derived from coal, of which our country is blessed with a very adequate supply.

In addition to the potential fuel savings by the use of alternate fuel sources, transportation fuel cells would greatly reduce pollutant emissions, which is already becoming a major problem in some of our larger cities.

Federal R&D emphasis over the past 10 years has been aimed primarily at the gas and electric utility industry. This effort is to be applauded since utility fuel cells are now near the point of commercialization. Similar emphasis for transportation should now receive Federal attention.

In addition to the enormous opportunities for alternate energy for transportation, our association would like to encourage Congress to consider the industrial applications of fuel cells which have the potential to improve our energy cost and therefore the global competitiveness of our industrial base.

Much of the past effort and expenditure on utility applications of fuel cells could be readily adapted to industrial use. A series of on-site, industry cost-shared experiments could probably give the added impetus to get the industrial applications moving. A logical first target could be the chlor-alkali industry which produces hydrogen and uses DC power.

In closing today, I would like to say that the Industrial Fuel Cell Association commends the foresight of Senator Matsunaga in introducing the legislation that we are considering today. The handwriting is on the wall. We are driving our energy economy with a depleting resource and are relying on a foreign fuel source of a most unstable nature. Our country must unshackle itself by becoming energy independent through the use of our renewable resources.

Further, we agree that the ultimate answer will include the production and use of hydrogen from these resources. We also believe that fuel cells with their high energy efficiency and very low air pollution emissions will become one of the ultimate prime movers of our country.

Today I have made some specific comments that we believe can strengthen the legislation before you. I hope they are of value to you and worth your consideration.

Mr. Chairman, I thank you for the chance to testify today.

Senator FORD. Thank you, Mr. Spillers.

Mr. Sturgeon.

STATEMENT OF EUGENE STURGEON, DIRECTOR OF EXTERNAL RELATIONS, NORTHEAST UTILITIES, ON BEHALF OF THE FUEL CELL USERS GROUP OF THE ELECTRIC UTILITY INDUSTRY, INC., ACCOMPANIED BY JEFF SERFASS, EXECUTIVE DIRECTOR, FUEL CELL USERS GROUP OF THE ELECTRIC UTILITY INDUSTRY, INC.

Mr. STURGEON. Thank you, Mr. Chairman. With your indulgence, I have asked Jeff Serfass, who is Executive Director of the Fuel Cell Users Group, one of the organizations that I am representing today, to sit with me.

Senator FORD. That is perfectly all right, and I am glad you identified him for the record.

Mr. STURGEON. Thank you.

I am Gene Sturgeon, Director of External Affairs for Northeast Utilities. Northeast Utilities is an electric and gas utility holding company under the 1935 Holding Company Act. We have properties in Connecticut and in the western part of Massachusetts.

I am here in support particularly of Senate Bills 1294 and 1295, and I don't mean to exclude Senator Matsunaga, but our comments are directed toward those two bills, although we commend you, Senator, for your initiative in introducing S. 1296 as well.

I would like to speak briefly as well about the status of fuel cell technology development from the standpoint of a users' group and the opportunity for its commercialization.

Northeast Utilities has been supporting the development of fuel cell technology for nearly 20 years. My company was one of nine electric utilities who joined with the United Technologies Corporation in the early 1970s to develop a multi-megawatt fuel cell power plant and to test a one megawatt demonstration unit. Northeast Utilities has continued to support the development of fuel cells since that time with both financial and manpower resources with the objective of ultimate commercial application of our system.

I am also here to speak on behalf, as I mentioned, of the Fuel Cell Users Group of the Electric Utility Industry. A list of the members of that group is attached as attachment 1 to my submitted testimony.

The Fuel Cell Users Group is an organization of 45 electric utilities and the national trade associations of the electric power industry, the Edison Electric Institute, the American Public Power Association, and the National Rural Electric Cooperative Association. The Users Group was established in 1980 to assist, promote and accelerate the development and electric utility application of phosphoric acid fuel cell technology.

The Fuel Cell Users Group and my remarks today will focus on that development and the application of phosphoric acid, multi-megawatt fuel cell technology.

As an aside, Northeast Utilities has also been an active participant in the gas industry's on-site 40 kilowatt program, including testing one of the 46 40 kilowatt units operated throughout the country. Additionally, we are presently investigating participation in the 200 kilowatt demonstration program. We also have a continuing interest in the long-term potential of molten carbonate and solid oxide technologies. However, it is the multi-megawatt, phosphoric acid technology that we believe offers electric utilities the early promise of a clean, modular, efficient electrochemical generation technology for siting and operation in both urban and remote locations.

The Users Group Management Committee, of which I am a member, has periodically reviewed in depth the development programs and commercialization plans of both International Fuel Cell Corporation and Westinghouse Electric Corporation. The potential value of fuel cell technology is growing in appreciation by utilities as the urban system of investor-owned utilities particularly and some of the public's make financial commitments to demonstration and long-term testing of 11 megawatt fuel cell power plants in a program structured by the Electric Power Research Institute. Whether or not sufficient private risk capital exists to complete formation of this demonstration program is a question yet to be fully answered.

The demonstration initiative to which I just referred is an effort to deploy several 11 megawatt power plants to be tested over a number of years in several different applications in order to obtain the longer term operating, reliability and cost data necessary for utilities to evaluate the competitive fit of this technology on their systems.

One public power system, the City of Palo Alto, California, has already approved formation of one test project. That project will include the support of a number of municipally owned systems throughout the country.

Several northeastern utilities are considering forming a similar consortium.

The price tag is expected to be high for these 11 megawatt units initially. The risks commensurately are also high. However, we believe the promise of their successful commercialization is great.

Senate Bills 1294 and 1295 demonstrate the continuing leadership of Congress in recognizing the potential of this technology. Congress has consistently funded fuel cell development over the years, fostering its evolution from one that can provide small but reliable generation packages for on-board spacecraft to one that is now nearly ready for electric utility application.

Unfortunately, support from DOE has not been as consistent. Delays in implementing funded programs to develop the advanced international fuel cell configuration B fuel cell stacks for electric utility size plants have resulted in an inability to incorporate this advancement in the current demonstration effort.

Further, the entire development program will not be completed for several more years due to contracting delays and a stretched-out and less than ambitious schedule for completion of the work. The capital cost of the mature power plant remains the chief obstacle to commercial application, and advanced stack technology is crucial to meeting this competitive goal.

Implementation of this fuel cell demonstration effort has also been hindered by ideological opposition to Federal support of the actual demonstrations. The cost of these several demonstrations, as I mentioned, is high, as high perhaps as $120 million. And many electric utilities are not in a position to accept the risks that this investment requires. The risk-sharing value of Federal participation as the private industry investment in these demonstration projects increases, therefore, is very important.

The program's progress to date is the result of about a half a billion dollars in private and public funding to develop the technology to the point that it is now ready for demonstration. The absence of DOE funding at this critical stage will make it nearly impossible for the United States to remain in its leadership position worldwide.

In today's regulatory climate, the utility may not always be rewarded for taking on the risks of a new technology. In tomorrow's regulatory climate when this technology will be commercially useful, the utility's role in building new generation has not yet been clearly defined. I believe that the investments being made by the manufacturers and the utilities must be complemented by public support if significant technological breakthroughs are to be achieved. Continued cost sharing of a large demonstration program is in my opinion not only necessary but the only realistic way to achieve commercialization in any reasonable time frame.

The Fuel Cell Users Group, therefore, supports Senate bills 1294, which proposes research and development that will broaden the application of this technology. We also support Senate Bill 1295 and the actions it proposes that will facilitate its commercial application.

Electric utilities nationwide are undergoing some dramatic changes as the industry moves into an era of deregulation of generation and transmission in a competitive environment afflicted with the uncertainties of ever-changing State and Federal regulation. FERC, State regulators and many electric utilities are questioning whether it is prudent to invest utility capital in risking new generation technologies. Despite the present uncertainties, I believe commercialization of this technology can be successful because of its importance to the many utilities and to their applications in the United States.

Let me conclude by reemphasizing that the Fuel Cell Users Group supports legislation which seeks to improve fuel cell technology and to widen its application. We find these elements in our support of Senate Bill 1294 and 1295. I urge your support for these bills and for adequate funding for continued technology development in the energy and water appropriations bills presently wandering through Congress.

This concludes my remarks, Mr. Chairman, and I certainly would be happy to respond to any questions.

[The prepared statement of Mr. Sturgeon follows:]

STATEMENT ON SENATE BILLS
S. 1294 and S. 1295, and
FUEL CELL RESEARCH, DEVELOPMENT
AND COMMERCIALIZATION

Presented to the

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

of the

COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

Eugene Sturgeon

Director of External Relations

Northeast Utilities

Hartford, Connecticut

on behalf of the

FUEL CELL USERS GROUP OF THE ELECTRIC UTILITY INDUSTRY, INC.

September 23, 1987

Mr. Chairman, I am Gene Sturgeon, Director of External Affairs for Northeast Utilities (NU) of Hartford, Connecticut. With me today is Jeff Serfass, Executive Director of the Fuel Cell Users Group of the Electric Utility Industry, Inc.[1] I am here in support of Senate Bills 1294 and 1295 and to speak about the status of fuel cell technology development and the opportunity for its commercialization.

NU has been supporting the development of fuel cell technology for nearly 20 years. Our company was one of nine electric utilities who joined with United Technologies Corporation in the early 1970s to develop multimegawatt fuel cell power plants and to test a one megawatt demonstration unit. Our company has continued to support the development of fuel cells, with both financial and manpower resources, with the objective of ultimate commercial application of this energy generation technology.

I am also here to speak on behalf of the Fuel Cell Users Group of the Electric Utility Industry, Inc. The Fuel Cell Users Group is an organization of 42 electric utilities and the national trade associations of the electric power industry: The Edison Electric Institute, the American Public Power Association,

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1 The Fuel Cell Users Group of the Electric Utility Industry, Inc., is a seven-year old organization with a membership of 45 utilities (and 11 associate members) spanning the privately, publicly, and cooperatively owned electric utility industry. A list of the membership is included as Attachment 1. The members of the Users Group represent about a third of the U.S. generating capacity. The Group is united in the interest of encouraging and supporting research, development, demonstration, and commercialization of phosphoric acid fuel cell power plants.

and the National Rural Electric Cooperative Association. The Users Group was established in 1980 to assist, promote and accelerate the development and electric utility application of phosphoric acid fuel cell technology.

The Fuel Cell Users Group, and my remarks today, are focused on the development and application of phosphoric acid, multi-megawatt fuel cell technology. NU has also been an active participant in the gas industry's on-site, 40-KW program including testing of one of the 46 40-KW units operated throughout the country. Additionally, we are presently investigating participation in the 200-KW demonstration program. We also have an interest in the long term potential of molten carbonate and solid oxide fuel cell technologies. It is the multi-megawatt phosphoric acid technology, however, that offers electric utilities the early promise of a clean, modular, efficient electrochemical generation technology, for siting and operation in both urban and remote locations.

The Users Group's Management Committee, on which I sit, has periodically reviewed, in depth, the development programs and commercialization plans of both International Fuel Cell Corporation and Westinghouse Electric Corporation. Before I offer our comments on Senate Bills 1294 and 1295, I would like to discuss the status of commercialization of this technology, the importance of the federal role today and the harm that deferrals and other discontinuities in federal support mean to this important development effort.

For many years, the manufacturers, the electric utility industry and the federal government have been promising that fuel cell technology will soon be commercial. The electric utility industry continues to be interested in this technology because it offers a uniquely clean and efficient power generation option in a time of limited technology choices. The value of fuel cell technology is being appreciated by utilities as urban systems make financial commitments to demonstration and long term testing of 11-MW fuel cell power plants in a program structured by the Electric Power Research Institute. Whether or not sufficient risk capital exists to complete formation of this demonstration program remains to be seen.

The demonstration initiative of which I speak is an effort to deploy several 11-MW power plants to be tested over several years, in several different applications, to obtain the longer term operating, reliability and cost data necessary for utilities to evaluate the competitive fit of this technology on their systems. One public power system, the City of Palo Alto, California, has already approved formation of one test project, with the support of numerous municipally-owned utilities throughout the country. Several other northeastern utilities are considering forming a similar consortium. The price tag is expected to be high for the 11 megawatt units. The risks are high, but the promise is great.

Senate Bills 1294 and 1295 demonstrate the continuing leadership of Congress in recognizing the potential of fuel cell technology. Congress has consistently funded fuel cell technology development over the years, fostering the evolution of the technology from one that can provide small but reliable generation packages for on-board space craft to one that is now nearly ready for large electric utility application.

Unfortunately, support of the effort by the U.S. Department of Energy has not been as consistent. Delays in implementing funded programs to develop the advanced International Fuel Cell Configuration B fuel cell stacks for electric utility-size plants have resulted in an inability to incorporate this advancement in the current demonstration effort. The entire development program will not be completed for several more years due to the contracting delays and a stretched-out, unambitious schedule for completion of the work. The capital cost of the mature power plant remains the chief obstacle to commercial application of fuel cells and advanced stack technology is crucial to meeting cost goals.

Implementation of this fuel cell demonstration effort has also been hindered by the ideological opposition to federal support of the actual demonstrations. The cost of these several 11-MW demonstrations is high (about $120 million) and many electric utilities cannot accept the risks that this investment presents. The risk-sharing value of federal participation, as the private industry's investment in demonstration projects becomes large, is very important. Not all electric utilities are in a position to accept this extraordinary risk today.

The program to-date is the result of 500 million dollars in private and public funding to develop the fuel cell technology to the point that it is now ready for demonstration. The absence of DOE funding at this critical stage makes it nearly impossible for the U.S. to remain in its fuel cell leadership position.

The advantages of this technology primarily accrue to the public, not the electric utilities themselves. The benefits of this improved technology will ultimately accrue to the utility ratepayers and the beneficiaries of environmental improvement. In today's regulatory climate, the utility may not be rewarded for taking on the risks of new technology - in fact, in many instances they are more likely to be penalized. In tomorrow's regulatory climate, when the technology will be commercially-useful, the utility's role in building new generation has not yet been clearly defined.

We believe, therefore, that the investments being made by the manufacturers and the utilities must be complemented by public support if we are to achieve significant technological breakthroughs. Continued cost-sharing of a large demonstration program is in my opinion not only necessary, but the only realistic way to achieve commercialization in any reasonable time frame.

The Fuel Cell Users Group, therefore, supports Senate Bill 1294, the "Renewable Energy/Fuel Cell System Integration Act of 1987," which proposes research and development that will broaden the application of this technology. We also support Senate Bill

1295, the "Fuel Cells Energy Utilization Act of 1987," and the actions it proposes that will facilitate commercial application of this technology.

Electric utilities nation wide are undergoing dramatic changes as the industry moves into an era of deregulation of generation and transmission in a competitive environment afflicted with the uncertainties of ever changing state and federal regulation. The Federal Energy Regulatory Commission, state regulators and many electric utilities are questioning whether it is prudent to invest utility capital in risky new generation technologies. Despite the present uncertainties, we believe commercialization of this technology can be successful because of its importance to many utilities in the United States.

Let me summarize by re-emphasizing that the Fuel Cell Users Group supports legislation which seeks to improve fuel cell technology and to widen its application. We support S.1294 and S.1295. We further urge your support for continued technology development through the 1988 Appropriations Bill.

Thank you once again for the opportunity to appear before the Subcommittee in support of fuel cell technology. I will be happy to respond to any questions or comments on my remarks.

ATTACHMENT 1

FUEL CELL USERS GROUP MEMBERS

Federal Government Utilities

Tennessee Valley Authority

Cooperatives

Adams Electric Cooperative, Inc.
Allegheny Electric Cooperative, Inc.
Buckeye Power, Inc.
Colorado-Ute Electric Association, Inc.
Lee County Electric Cooperative, Inc.
National Rural Electric Cooperative Association
Southern Maryland Electric Cooperative
United Power Association

Municipals

American Public Power Association
Austin Electric Department
The Easton Utilities Commission
Jacksonville Electric Authority
Lincoln Electric System
Los Angeles Department of Water & Power
Missouri Basin Municipal Power Agency
Omaha Public Power District
Palo Alto Electric Utility
Provo City Power Department of Utilities
Salt River Project Agricultural Improvement & Power District
Santa Clara Electric Department
Taunton Municipal Lighting Plant

Investor Owned Utilities

Boston Edison Company
Carolina Power & Light Company
Centerior Energy Corporation
Consolidated Edison Company of New York
The Dayton Power & Light Company
Delmarva Power & Light Company

Investor Owned Utilities (cont.)

Edison Electric Institute
Hawaiian Electric Company, Inc.
Idaho Power Company
Northeast Utilities Service Company
Northern States Power Company
Ohio Edison Company
Pacific Gas & Electric Company
Philadelphia Electric Company
Public Service Company of Colorado
Public Service Company of Oklahoma
Public Service Electric & Gas Company
San Diego Gas & Electric Company
Southern Company Services, Inc.
Tampa Electric Company
Utah Power & Light Company
Virginia Power Company

Foreign

Sydkraft, Ltd.

Associate Members

Bechtel Group, Inc.
Burns & McDonnell Engineering Company
Combustion Engineering, Inc.
Ebasco Services, Inc.
The National Commission for Research & Development of Nuclear Energy & Renewable Energy Sources
Gilbert/Commonwealth, Inc.
Hydrogen Industry Council
Johnson Matthey Research Centre
Kinetics Technology International Corporation
New Energy Development Organization
Stone & Webster Engineering Corporation

August 11, 1987

Senator FORD. Thank you very much. Let me ask questions of both of you, and you can respond either agreeing with the other one or having a somewhat different opinion.

What are the benefits to be gained from a federally sponsored fuel cell research program, and is $5 million provided in S. 1294 an adequate amount? Mr. Spillers, do you want to start first?

Mr. SPILLERS. What would be gained? I still feel like there is new fuel cell technology that is out there today that offers the hope—well, I keep going back to the transportation industry. I keep saying that is a major fuel user in this country. And I see the renewable energy called for in Senate Bill 1294 as a way to produce hydrogen for fuel cells for transportation, for instance.

A lot of the renewable power systems, such as solar power, will not generate electricity around the clock. They are going to have to store backup power some way. You can store them in batteries which are hard to transport. The other way I would think of would be to store it in hydrogen. And that's my interest in 1294.

I don't know that the one year, $5 million funding called for is adequate for that. That is my opinion on that one.

Senator FORD. Mr. Sturgeon.

Mr. STURGEON. I think, Mr. Chairman, that you'll find that most of us feel that no amount of funding is adequate to do the job that we want to do. But if you look at the breakdown where that funding is going and you specifically apply a portion of it in a partnership between the Federal Government and the utility industry, both the private and the public sector, in a commercial application of a demonstration project that will lead us ultimately to commercialization, I think that money will be well-spent.

Senator FORD. Well, both of you apparently represent the private industry group. And what do you all see as the role of private industry in fuel cell research and development?

Mr. SPILLERS. I might speak to that first.

One of the problems—and I am going back again to the transportation thing because I keep seeing that as a major user of hydrogen. It is already a major user of fuel, of course. And the problem I see is that there are things happening in the transportation industry. It is moving very slow. Things, of course, are all market driven. There is no screaming cry for fuel for our automobiles now. Gasoline is relatively cheap now. Tomorrow morning when we wake up, it may be relatively expensive. We never know. We have to watch that every day.

So, I don't see, for instance, the automotive industry moving fast enough to meet the probable deadline for coming up with non-imported fuels. So, I see the government, for instance—just an idea is to have an incentive reward out there even where you could challenge the automotive industry. Hey, you come up with a prototype automobile within a certain period of time that meets certain specifications, and you win this gold ring. You see?

But I am worried about the transportation moving fast enough, I guess, is the bottom line. The market forces are not there. Gasoline is not expensive enough. When it becomes expensive enough, as I said, possibly overnight, it will be too late. And I see the Federal Government as representing all the people in this country as a way to get this thing going. And it will not go until the last minute, I'm afraid to say.

Senator FORD. Mr. Sturgeon, do you have any comment?

Mr. STURGEON. Yes, I would like to from the utility industry standpoint.

I think that if you look at what has transpired historically in the utility industry with respect to research and development into emerging technologies—and I think the best example probably is the history of the development of nuclear energy—the electric utility industry has always been interested in alternative sources of electric power generation to meet our country's needs and our own customers' needs regionally and locally.

While we all have our own agenda—that is, the 180 odd investor-owned utilities and the many publics in this country—nevertheless, the end objective is to provide an adequate, reliable, cost efficient source of energy.

When we look at the fuel cells in today's climate—and remember now, as I said in my prepared remarks, we have been looking at this program and its various components for more than 20 years. We feel that we need the diversity that this option can offer to us if it is brought to commercialization. We need to develop this diversity in the best climate that we can develop it. And that involves both the private and the public sector at this stage of development.

What it is going to give us is another tool, another source of electric power generation that adds to the flexibility of many of the utility systems in this country. And I would conclude that statement by saying—and I am sure, Senator Ford, having sat in on many, many energy committee meetings, you know that the utility industry today is struggling with the problem of whether or not to build any more large base load generating facilities, and if so, what kind of facilities those may be.

This particular R&D program and demonstration program fits right into the middle of that jigsaw puzzle at this time.

Senator FORD. Mr. Spillers, I might tell you that—you were talking about methanol, for instance, use as fuel for automobiles. Ford Motor Company came down with an Escort with a sensor. And they could tell the engine what is in the tank since we do not have the ability to go by and pick up methanol just anyplace. Methanol doesn't have the distribution system.

The only thing they ask is that the applied miles per gallon for their fleet—give them a better average maybe. If they were working with this model, it might ease up some on some of their larger models. And that didn't fly very well with the Commerce Committee.

Of course, I was very anxious to see that move coming from the largest coal producing State in the Nation. I was interested in seeing the carrot there. And they asked for it. They said if you will help us here, we will expedite it here. But we couldn't get the energy committee interested in that.

Let me ask another question about S. 1295. It directs the International Trade Administration to examine the export potential of fuel cells. What do you believe the prospects are for export of these technologies?

Senator MATSUNAGA. Well, I think the prospects will be good for the winner in this race. I just so happen to have a little book here I think in my briefcase. For instance, it shows fuel cell R&D in Japan. We don't even have anything like this in the U.S. There is no publication like this in the U.S. You go through here and, as we know, there is much activity, as Senator Matsunaga said earlier, in all the countries. So, I think the ones that develop the technology first will be the ones that get the export market.

And again, back to transportation, the airplane, the automobile—it's a way to have competitive technology in our country that we can throw back overseas. I am especially interested in the automobile industry. I think it is a way to regain our leadership in automotive technology by offering something that is better, nonpolluting, more energy efficient. And someone is going to take it, and I would like to see it be the U.S.

Mr. STURGEON. I would like to just add a comment, if I might.

Senator FORD. Yes, sir.

Mr. STURGEON. I would not like to see this country become or the utilities of this country become a net importer of a technology that we fathered. And I think we have the potential to avoid that.

Senator FORD. Well, let me just tell you this Senator went to Illinois to the lab there that had developed the superconductor/supercollider, a great basic breakthrough. And I was interested in the funding and who was in on it. And they said, well, there it is. And I think there were six or seven groups from Japan that had been in it all along. They had put millions of dollars into it, and they have now taken that research. We are sitting here patting ourselves on the back wondering what we are going to do to get the rest of the money to move on. And we are going to have a big competition and that sort of thing. And the Japanese are moving the heaven and earth day and night to move on with the superconductor. So, it indicates where we are going with all of this.

Mr. Spillers, you said that we will have an energy shortage beginning when?

Mr. SPILLERS. I think I was quoting the Congressional Record——

Senator FORD. Okay.

Mr. SPILLERS [continuing]. As saying that we have enough proven reserves to last nine years. That is proven reserves as of about right now. Now, we may find more reserves, but right now we have nine years of proven reserves.

Senator FORD. In what now?

Mr. SPILLERS. In petroleum——

Senator FORD. Petroleum.

Mr. SPILLERS [continuing]. In this country.

Senator FORD. Well, we are importing—I think several times in the last 30 days we have imported more than 50 percent per day.

Mr. SPILLERS. Excuse me, sir. The imports—my understanding—are down over a few years back, but they are projected to grow right back where they were.

Senator FORD. I think imports were 30 percent when they had the embargo in 1973, and they are now nearing 50 percent now in 1987. So, if they turn the spigot off—everybody has flutters over the Persian Gulf, you know. We have 26 Iranians, and we can't call them prisoners of war. They are detainees. And we are trying to find out some way that somebody will take them back. We want to give them back today very badly. That's just a side comment.

You commented, Mr. Spillers, that coal—we had a long term. There's a false impression about coal also. There are the known reserves, but there are also the retrievables. And when you begin to subtract the coal that is not retrievable, you get down really to our basic reserve. And that is reduced somewhat close to I think 51 percent of the reserve. That becomes then the reserve. So, we really don't have all of that ability as it relates to coal.

Of course, if we are getting clean coal technologies, we can take some coal under the circumstances. That would increase our reserve some. But if you pass a .6 emission standard, you have 1 percent of the known reserves of coal in eastern Kentucky that could be burned directly. So, you have eliminated that resource overnight.

Mr. SPILLERS. Right.

Senator FORD. So, we have more problems than people want to admit I think. And some of us will want to go back and say I told you so. I don't want to ever do that. I would like to see us in a position where it would never happen to us.

Mr. Sturgeon, you said something that bothered me just a little bit since this is the energy committee. "Industry moves into an era of deregulation of generation and transmission." That indicates that you have got some interest in FERC's position as it is traveling down the deregulation pike. I think there is going to be one hellacious fight over that. I just wanted to indicate that to you now.

Do you have any reason to believe that there will not be some concern by your public service commissions in the States and that sort of thing where FERC is going to usurp their rights?

Mr. STURGEON. In areas where FERC is moving in that direction, I know that the State commissions individually and collectively at the NARUC level are very much concerned, as are we. Our business, while we are a registered holding company, is only about—well, I guess it is less than 10 percent of our business is done with FERC. The balance is done with two State commissions. And even though two State commissions have some different views.

We are concerned, however with the speed with which they move down this path. We, as I indicated, are in business in the State of Massachusetts, and the State of Massachusetts has pioneered in the competitive bidding process for qualifying facilities under PURPA. As far as Connecticut goes, they are moving a little more deliberately at this point in time. And of course, we are watching not only that at FERC, but we are watching how they intend to treat independent power producers and whether, in fact, we as a utility company operating in either one of those two jurisdictions will be a player in our own ball field in providing electric generation for our customers in the future.

It is of serious concern to us. In fact, our estimates are that we have a potential for losing somewhat on the order of 20 percent of our total industrial customers' generation needs in the next few years if we are not out in front with some competitive relationship to what is going on at the Federal and State level.

Senator FORD. That's all the questions I have. I got off the subject maybe just a little bit, but it is still all related I think.

Senator Matsunaga, do you have any questions?

Senator MATSUNAGA. No questions, Mr. Chairman. You asked them all.

Senator FORD. I took your list and went down it very well, didn't I?

Thank you very much, gentlemen. It was a pleasure to have you as witnesses today.

It always happen to a southern boy. He has to pronounce some of these names. I may have to call on you, Senator Matsunaga.

The Director of the Center for Electrochemical Systems and Hydrogen Research, Texas A&M University, A. John Appleby; and Director, Hawaii Natural Energy Institute, Dr. Patrick Takahashi. And now we come to the one that bothers me considerably, Director of Clean Energy Research Institute, University of Miami, Veziroglu.

Dr. VEZIROGLU. Veziroglu. That's right.

Senator FORD. Well, I am doing better. It's beyond four letters, too.

So, Dr. Appleby, we will have you go first, and then we will go to Dr. T. How's that? [Laughter.]

Dr. Appleby, please.

STATEMENT OF DR. A. JOHN APPLEBY, DIRECTOR, CENTER FOR ELECTROCHEMICAL SYSTEMS AND HYDROGEN RESEARCH, TEXAS A&M UNIVERSITY

Dr. APPLEBY. Thank you, Mr. Chairman.

Mr. Chairman and Mr. Matsunaga, I am delighted to be here today to testify before this subcommittee on S. 1294, 1295 and 1296, which we——

Senator FORD. Just a minute please. We don't have a large crowd, but most of the Federal witnesses are leaving. Therefore, they take all their bureaucrats with them.

Go ahead, Dr. Appleby.

Dr. APPLEBY. Thank you, sir.

Which we heartily endorse. I would like to start out by saying that, first of all, I have a complete written testimony for the record.

Senator FORD. That will be included in the record in total, Doctor.

Dr. APPLEBY. Thank you, sir.

And today what I will try to do is to make some comments in regard to some of the statements that Secretary Fitzpatrick made, and also to try to summarize my written testimony in as short a way as I possibly can.

Well, as Miss Fitzpatrick did point out, hydrogen is already a very important industrial chemical. And it is, in fact, quite a bit more important than she indicated. In fact, it is on a weight basis, the third most important chemical compound produced in larger quantities than anything.

Senator FORD. Just a minute, Doctor. We have got a vote.

Dr. APPLEBY. Yes.

Senator FORD. We have a vote on and so one of us will be here and we won't have a disruption. He is going to run over and run back. I am going to walk over and walk back. See, he's a lot younger than I am.

Pardon me, Doctor. Go ahead.

Dr. APPLEBY. Yes, sir, that's fine.

I was saying that hydrogen is produced in larger quantities, in fact, than any other industrial chemical. In fact, it is only exceeded on a weight basis by steel and sulphuric acid. This is something a lot of people do not realize.

And we also have to bear in mind that hydrogen is the lightest element. And therefore, on an atomic basis more hydrogen atoms or molecules are produced than any other industrial chemical today. However, it is not normally seen because it is all used internally, inside industry particularly, for instance, in petroleum refining.

Another point that she made, which I found very confusing—in fact, I think members of the academic and engineering community here found rather confusing—is her statement that it takes 4 to 15 times as much energy to produce hydrogen from some primary energy source. Well, I'm afraid I don't really understand that at all.

When one considers an energy source, one has to remember that it has to be transformed into something useful, and something useful means work. And work ultimately means really electricity.

Now, if one converts coal directly into electricity in the traditional manner, one does it at an efficiency of about 38 percent. However, using known technology, which I will describe very briefly later, if one converts coal into hydrogen, one can do it at 65 percent efficiency. And with waste heat recovery, that hydrogen can be converted into electricity overall at 45 to 50 percent efficiency from coal. In other words, conversion of coal into hydrogen as an intermediary can produce electricity at a higher efficiency than coal directly.

Similarly, coal can be converted into gasoline at a similar efficiency to hydrogen, say, 65 percent. But gasoline used in an IC engine is converted into work at only an efficiency of perhaps 15 percent; whereas hydrogen can be converted into a fuel cell directly at up to 60 percent efficiency.

And this is really what I am trying to stress here. Hydrogen is a very interesting fuel, a very advantageous fuel from the energetic viewpoint.

But I think we are here today to emphasize another aspect of hydrogen which is the fact that it has tremendous advantages from the environmental point of view over today's fuels. And I am not talking about the microenvironment. I am talking about the global environment.

On July 16, Dr. Frank Press, the President of the National Academy of Sciences, testified before the Senate Subcommittee on Science, Technology and Space concerning the greenhouse effect. And his studies at the National Academy have come to the conclusion that sometime toward the year 2000, we will have to stop burning fossil fuels altogether. And hydrogen will then be the only suitable fuel because it will be the only material that will not put CO_2 into the atmosphere.

Well, what I am going to say today is that I agree with that in principle. However, I would like to point out that there are ways of using our available fossil fuels, particularly coal, in such a way that CO_2 is not put into the atmosphere; and in other words, we can avoid the greenhouse effect until such time that we have a sufficient number of new inventions and research developments to allow us to produce hydrogen from either solar sources or from something not invented yet, for instance, perhaps nuclear fusion. I do not know.

However, there is no question about the fact that the greenhouse effect will have to be taken seriously in the future even though we do not presently know what the ultimate results will be. There will be a change in the world's climate. That we do know. There will be some changes in the ocean levels. And once CO_2 is in the atmosphere, no artificial means can remove it. The only way will be to wait for the natural processes to take place of absorption of CO_2 into the oceans, which we know take about 10 centuries. And we cannot afford to wait that long.

So, I do believe strongly that research on hydrogen production, storage and its efficient use will be necessary throughout the world, not just in the United States, as if you like, an insurance policy to preserve the historically accumulated capital in civilization for future generations. It will also in the, perhaps, shorter term give the U.S. the possibility of creating new jobs and have new equipment available for export. And that is certainly the attitude in Canada, as we have already heard, in Japan, in West Germany, France, the Netherlands, et cetera.

France is now, for instance, involved in the building of a 20 megawatt advanced electrolyzer using nuclear electricity as the power source to produce liquid hydrogen for the Ariane space program. Already the 2.4 megawatt prototype advanced electrolyzer using this power source is in operation.

Society requires two energy sources, one that can be used instantly, and that is electricity and the most convenient energy source of all; and it needs a storable fuel for convenience for the utilities for peaking purposes and also, of course, for applications where electricity is not appropriate, such as in traditional transportation and automobiles. Now, hydrogen will have to be the latter fuel in the future.

Objections are often raised to the high cost of hydrogen. And if one looks at renewable hydrogen, as Mrs. Fitzpatrick indicated, based on present technology and present extrapolations I will have to admit the cost is too high, many times higher than the cost of traditional fuels, natural gas for instance.

However, at Texas A&M University and elsewhere research is being done on ways of producing hydrogen using solar energy which should be infinitely cheaper than anything we have today. Some of these involve genetic engineering. They would, indeed, involve the attempts to genetically engineer the chloroplasts that are present in living plant matter which would directly produce hydrogen from sunlight without any capital investment at all. And this sort of thing is presently a dream, but it is certainly something which will probably become reality sometime in the early 21st Century.

However, in the meantime, I would like to talk about fossil hydrogen or rather hydrogen produced from fossil energy such as coal without any pollution whatever at the source. And already we have an operating plant in Southern California, the cool water combined gasifier, combined cycle system, which provides a sort of prototype for this. In it coal, of course, is gasified to produce a hydrogen rich gas which is burned in a gas turbine with heat recovery to raise steam, and overall electricity can thereby be produced at an efficiency of about 45 percent.

The Electric Power Research Institute has examined various advanced plants of this type, along with Fluor Corporation, to see if it is possible to have a system which would be more economically attractive in the future. And this is based on the fact that, as we all know, electricity demand is cyclical, whereas the gasifier, a chemical factory, would like to work all the time at full output. And in this case the best thing to do is to co-produce electricity and hydrogen, or electricity and some other fuel. In the first examination here, the fuel was methanol, and that methanol could be stored and used for peaking purposes, made at times when electricity demand was low.

Well, in the second iteration of this system, it is possible to produce CO_2 from the coal gas hydrogen and electricity simultaneously according to the required demand. And the hydrogen can be used as a fuel, and the CO_2 will be a valuable byproduct which will be initially used for enhanced oil recovery. When that infrastructure is no longer needed—that is to say, when the oil has run out—the CO_2 can then quite simply be disposed of by pipelines that are already in place in the depleted oil wells. And this we see as a way of producing hydrogen without any pollution at source whatever, burying the CO_2 underground, ultimately perhaps getting rid of it in the oceans. That is certainly a long-term alternative.

The interesting thing about this is the CO_2 that is produced is worth something like $5 or $6 per million Btu of hydrogen produced. The electricity, of course, is also a subsidizing byproduct. And the total cost of that hydrogen without the subsidies is about $7 per million Btu. And this would compare with hydrogen produced these days from natural gas at, say, $10 per million Btu, or the cost of gasoline without tax, which is perhaps $5 per million Btu at the moment. So, hydrogen, contrary to what Secretary Fitzpatrick indicated, is not necessarily going to be a very expensive fuel.

Now, what I would also like to point out here is that——

Senator MATSUNAGA. Please.

Dr. APPLEBY. Yes, Senator Matsunaga.

I had just summarized some of the methods of producing hydrogen without polluting the atmosphere with CO_2, which you alluded to in your remarks, for instance, disposing of the CO_2 in the oceans, which might be appropriate in certain locations, and in an extension of the cool water plant in Southern California, using that CO_2 initially as a chemical for enhanced oil recovery, and then eventually disposing of it down depleted oil wells. And this is certainly an option for the future. All of these, indeed, put no CO_2 into the atmosphere.

Now, the point I am now going to make is the fact that whereas hydrogen produced by these methods using the subsidizing effect of electricity and CO_2, will be reasonably competitive with gasoline and will certainly be competitive with natural gas extrapolated in cost by the Electric Power Research Institute beyond the year 2000 when it is expected that natural gas will be on the order of $10 to $15 per million Btu, we also have to take into account the efficiency of use of hydrogen. Hydrogen in fuel cells—and hydrogen fuel cells are extremely simple compared with today's fuel cells since they require no fuel processor, costing 80 percent of the total cost of the unit, which turns essentially the fuel into hydrogen. Such units can consume hydrogen at up to 60 percent efficiency compared with, say, IC engines producing energy at only 15 percent efficiency from gasoline.

And this to the consumer will mean that hydrogen will be a cheaper fuel than today's fuels, and certainly very much cheaper than the fuels available after the year 2000.

And in addition, since its end use efficiency is very high, the capital investment required for the infrastructure will be correspondingly lower. And this is going to be extremely important for the very capital intensive energy economy that we will expect in the future.

Now, I would like to very, very rapidly add a future dream here. Since the beginning of the year, we have heard a great deal about the new so-called hot superconductors, which can operate at temperatures of liquid nitrogen or even beyond towards room temperature. However, under those conditions, they operate at very low currents and require large diameter cables which you could never afford.

To compensate for this high cost, we would have to use currents at least 100 times those available on copper conductors, and this requires, interestingly enough, because of the physics of the situation, going down to even lower temperatures. And in this case we can envisage the possibility of having a superconducting pipeline with electricity and hydrogen co-produced from cool water type plants or, indeed, from solar energy in which the hydrogen serves as a refrigerant and is tapped off, where required, as a fuel as will be the electricity. And this joint subsidy of one energy form required for one purpose with another form required for another strikes me as being a very interesting way of integrating our energy future.

Finally, I would like to make a point which I think will be reiterated by Dr. Veziroglu, and this is the fact that clean energy, such as hydrogen, cuts hidden costs, a sort of tax on society, which currently occurs due to the use of fossil fuels. This can be interpreted as such things as health costs, days off work, even reduced lifespan in the human terms, and in addition to that, of course, all the other environmental costs which Dr. Veziroglu estimates at $400 billion a year and rising.

The human costs appear to be about 6 percent of the present GNP. Currently fuel costs—that is to say, primary energy costs—are about 5 percent of the GNP. So, it is very interesting that these costs are even higher than the costs of the use of the fossil fuel alone, the production costs of the fossil fuel.

And to put that into another perspective, total health costs are about 11 percent of the GNP at the moment, and there are some thoughts that as much as 6 percent of the GNP consists of human costs which are partly health costs and partly lost productivity costs which result from the burning of fossil fuel.

Well, this just shows, as you said this morning, sir, just how precious hydrogen might be in the future.

I have already mentioned fuel cells. And I truly believe, as some of the other earlier witnesses stated, that fuel cells in vehicles using hydrogen will be the way to go. With an efficiency at least twice as high as present systems with no requirements for fuel conversion on board, compact units, in fact, based on the United Technologies SDIF or fuel cell system in a terrestrialized form, should be capable of producing the kind of power densities that we would require for vehicles in the future. And I would strongly recommend that this be looked at in terms of the hydrogen program or the proposed hydrogen program.

I think overall hydrogen has opportunities that cannot possibly be ignored. However, there is no doubt that it is being neglected. And as a very small example, Senator Matsunaga, we at Texas A&M University Hydrogen NSF Center, which was founded 5 years ago, and at the University of Miami Clean Energy Institute, which has been active for about 15 years in hydrogen research and information, were very disappointed to find ourselves left out of the Senate version of the energy and water development appropriation bill, H.R. 2700, although the Hydrogen Natural Energy Institute and the Florida Solar Energy Center were included in both versions. We were in the House version, but unfortunately, we seemed to have slipped out of the Senate version. And we would like to bring that to your attention.

Thank you very much.

[The prepared statement of Dr. Appleby follows:]

82-464 0 - 88 -- 5

A. J. Appleby: Testimony Before the Senate Committee on Energy and Natural Resources, Subcommittee on Energy Research and Development, Chairman, Wendell Ford (D-Kentucky), September 23, 1987

I wish to thank the Chairman and members of the subcommittee for the opportunity to be able to testify today on the future use of hydrogen fuel, with its conversion to work in fuel cells, in the future world energy economy. My name is Dr. John Appleby, Professor of Applied Electrochemistry and Director of the Center for Electrochemical Systems and Hydrogen Research, Texas A&M University, College Station, Texas 77843. We are constantly being informed of the future importance of the "Greenhouse Effect" on the global environment. This will result from the build-up of atmospheric carbon dioxide (CO_2) due to the man-made emissions, which result from burning fossil fuels in increasing amounts as world economic activity continues to grow. The balance between the CO_2 level in the atmosphere, in the biosphere, and in its ultimate sink, the oceans, is very delicate and is still not well understood. However, it is undeniable that the preindustrial level of CO_2 was about 280 parts per million (ppm), whereas in 1960 it was 315 ppm (with seasonal variations), in 1970 325 ppm, and about 345 ppm today. Assuming a continuation of today's scenario, it will reach 500 ppm by the middle of the next century.

Since CO_2 absorbs the long wave-length infra-red rays emitted from the earth's surface, while allowing sunlight to pass, an increase in CO_2 level will be expected to increase the average temperature of the atmosphere. This effect should be enhanced as the level of other "greenhouse" gases, such as that of methane from biological sources, particularly those associated with improved farming techniques required to feed the increasing world population, also go up from their preindustrial levels. All the above is summarized in Ref. 1.

An increase in atmospheric temperature may drastically alter climate and ultimately change the world as we have known it in historic times. This change will be much more rapid than has previously been the case in prehistoric or historic climatic cycles. While some geographic regions may profit, others may suffer severely. As an ultimate example, melting of the Antarctic ice-cap could raise ocean levels by 200 feet, which would drown many of the earth's most heavily populated land areas.

I attempted to discuss the above in more detail in my testimony before the House Subcommittee on Energy Research and Development on July 9, 1987 [2]. On July 16, 1987, Dr. Frank Press, President of the National Academy of Sciences, expressed similar opinions before the Senate Subcommittee on Science, Technology and Space and the National Ocean Policy Study of the Committee on Commerce, Science and Transportation. His testimony included a detailed account of the research the National Academy of Sciences is supporting on studies of the earth's atmosphere, climate, and the "Greenhouse Effect." In oral testimony, Dr. Press stated that we should be prepared to cease burning fossil fuels in the near future, to preserve the earth's general environment in something like its present form for future generations. In my July 9 testimony, I stressed the fact that maintenance of a reasonable atmospheric CO_2 level lying somewhere between today's value and some (to-be-determined) future limit requires either the use of a future fuel that does not contain carbon at all, or one that uses recycled atmospheric CO_2. Since all fossil fuels (coal, lignite, oil, natural gas) contain carbon, and a fuel using recycled atmospheric CO_2 (e.g., biomass fuels such as wood or agricultural waste and their products) is by definition non-fossil, the implication is that all future fuels should be non-fossil if the atmospheric CO_2 burden is to be maintained.

This is the basis of Dr. Press' argument: the only possible future fuels should use biomass products or should be derived from non-fossil sources that do not use geological carbon as a chemical building-block. While this approach is highly desirable in principal, in practice (at least based on present knowledge) it would be disadvantageous in many respects. For example, biomass derivatives as a universal fuel would require a substantial increase in farming effort and a huge and very capital-intensive transformation industry. This is not to suggest that biomass-derived fuels have no place: indeed, they can be of considerable local importance, for example in Hawaii, as is suggested by the research and development effort at the Hawaii Solar Energy Institute (University of Hawaii). However, on a national scale, biomass is likely to only make a small (though important) contribution to the energy economy, as was suggested by the testimony of Dr. D. Klass before the House Subcommittee on Energy Research and Development on July 9, 1987.

Of more importance in the ultimate 21st century energy future will be a non-fossil non-carboniferous fuel. The only real possibility is hydrogen produced by the splitting of water into its elements by the use of energy. The combustion of this hydrogen with atmospheric oxygen, the only product being steam or pure water, will provide the energy for future society for the applications where liquid or gaseous fossil fuels are used today. The use of hydrogen fuel will be entirely non-polluting if it is combusted in the correct manner, and its use will therefore completely eliminate acid rain (sulfur compounds and nitrogen oxides), the depletion of the ozone layer, and of course the build-up of atmospheric carbon dioxide. Last but not least hydrogen fuel will eliminate the "social costs" of burning fossil fuels, described below. This later 21st-century dream has been termed the "Hydrogen Economy" [3], and it may be regarded as the ultimate energy economy for mankind. It is ecologically sound because hydrogen, the storable fuel, is produced by splitting water where energy is available, and the only product of hydrogen is water, which is recycled via the natural process of the atmosphere.

Reference has been made in the last paragraph to the "social costs" of burning fossil fuels. These represent the hidden costs of the impairment to society as a whole as a result of using these fuels. Simple examples are the damage resulting from pollution and acid rain on structures (corrosion, erosion) and to natural resources (forests, etc.). Less obvious, since they are thought of as everyday hazards, are the insidious effects on health, including respiratory disease, lung damage and possibly cancer caused by particulates, days lost from work due to health problems, and shortened life-spans in the population as a whole. These health costs represent a "tax" on the GNP, which has been estimated as being as much as 6% of the GNP, or equivalent to about $3.67 (1986) per million Btu of fossil fuel consumed [4], based largely upon U. S. Government statistics [5]. To put this in perspective, total health costs are about 11% of the GNP. While the figure of 6% may be high, it is clear that the pollutional costs of fossil fuel use represent a considerable "tax" or loss to the GNP as a whole, probably exceeding the original market cost of the fuel (about 5% of the GNP). Other social costs of fossil fuel, principally their known environment impact, seem to be about as high as the human costs [4].

The above social costs may amount to a total of 15% of GNP, so that total fuel costs are effectively 20% of total economic activity, whether expressed as direct costs or loss of output. However, if the "Greenhouse Effect" due to CO_2 buildup is taken into account, then the total effective cost will be much higher. At present, it is impossible to give a reasonable figure for this, but it could be immense, since it would involve a total reconstruction of the civilization we have today, which represents the cumulative effort of many human generations.

Before discussing the production and ultimate direct cost of hydrogen fuel, we might consider the possiblity of controlling the "Greenhouse Effect" by artificially removing CO_2 from the atmosphere, rather than waiting for centuries for it to reequilibrate with the oceans, via the natural cycle. Cost of gas clean-up increases with dilution, however. As an example, the cost of removing CO_2 from rich gas derived from coal, where it is present in up to 20 volume % (after chemical transformation of carbon monoxide) is estimated to be about $0.65/MSCF (thousand standard cubic feet). In contrast, removal of CO_2 from stack gas in a coal-burning power plant (about 10-12 volume % CO_2) will cost $2.50/MSCF [6, 7]. Its removal from the atmosphere at say, an ultimate level of 500 ppm (0.05%) would be an impossibly costly task with any known technology, as would attempts to control CO_2 emissions by the use of individual chemical adsorbers on, say, vehicle exhausts. Finally, the use of control via biomass will not reduce the atmospheric CO_2 level: while an increase in CO_2 accelerates plant growth, respiratory and decay rates result in a natural equilibrium.

Accordingly, at some point in the early 21st century we will be forced to stop adding to the atmospheric CO_2 burden. This effort must be on a world-wide scale, which will require cooperation between all industrial nations. Such an effort may have very positive effects on geopolitics as a whole. Society requires two energy vectors, electricity, for immediate use at high efficiency, and storable fuels for use in peaking and mobile applications. Fossil fuels are largely used for both applications now. Future electricity production if it is from classical non-fossil sources (e.g. hydro, nuclear) will avoid the CO_2 problem, but hydro resources are limited and the total social costs of nuclear power are likely to be high. Fusion may be no better from the ultimate cost viewpoint than fission, and besides it is still very early in the development cycle. An all-nuclear economy, producing electricity as required, which was originally the basis of the proposed hydrogen economy [3] is therefore improbable.

The ultimate dream is an energy economy based on solar energy, producing electricity and hydrogen via photovoltaic processes [8]. However, for a long time to come, the capital costs of solar systems, and their low annual utilization will make them unattractive. For example, Baltimore Gas and Electric, in a recent study, have concluded that by 1995 solar photovoltaic panel costs may be about $1000 per peak kilowatt, but balance-of-plant and construction costs may total $1300/kW, yielding electricity at about 25¢/kWh, or three times today's costs. If this electricity were used to produce hydrogen from water via electrolysis, its cost would be over $80 per million Btu, or many times that of today's fuels. The capital requirements for such an economy would be unsustainable as Ref. 2 (and references therein) points out. This is not to say that economic solar hydrogen and photovoltaic plants are impossible: we are still early in the R&D stage for these technologies, and costs will be reduced and new inventions discovered with further research. Solar hydrogen must be supported by research funding: the ultimate dream, based on what we know today, would consist of an array of oriented, microscopic thin-layer solar cells of tandem multifunction type, efficiently absorbing several photons of different energies in series from sunlight so that enough voltage can be developed across their opposite catalyzed and protected faces to decompose water. Such cells, mounted in anionically conducting water-saturated thin plastic membranes, could produce hydrogen for use on one face and reject oxygen on the other, all at an overall efficiency of perhaps 20%. Such a system could be ultimately very inexpensive from the materials and production viewpoint. It is presently being examined at the Center for Electrochemical Systems and Hydrogen Research at Texas A&M University, with other supporting work elsewhere, unfortunately on limited funding.

While we have kept stressing hydrogen as a fuel from the environmental viewpoint, it also has an enormous advantage over fossil fuels in that it can be turned into useful work very efficiently via fuel cells. The latter can only use fossil fuels if they are first converted into hydrogen-containing mixed gases by fuel processors, which represent a major part of the capital cost of fuel cells being offered commercially today. Fuel cells with bulky fuel processors are unsuitable for transportation use, so fossil fuels must be burned in heat engines (e.g. internal combustion engines in vehicles) at low efficiency (typically about 15% in real use). Hydrogen, in contrast, can be directly used in fuel cells, particularly inexpensive alkaline-electrolyte systems requiring no rare catalysts, at 55% efficiency using today's technology. Hydrogen and fuel cells are synonymous, and federally-supported research and development is required on both if we are to avoid the environmental and economic consequences of the "Greenhouse Effect."

Finally, we have stated that solar hydrogen and electricity, while desirable, will be too expensive for wide use for some decades to come. The recommendation of Dr. Press is therefore not an economic reality today. However, we can avoid introducing CO_2 into the atmosphere not by eliminating the use of fossil fuels (particularly coal) totally, but by using them more intelligently. Coal from domestic sources can be the solution to the "Greenhouse Effect," and to ultimate energy independence. The Electric Power Research Institute has studied the coproduction of electricity and fuel from coal using an integrated gasifier combined cycle plant with low SO_x and NO_x emissions similar to the experimental Cool Water plant in Southern California [9]. Electricity demand is cyclic, whereas the gasifier operates at constant load, so the fuel (methanol in the initial study) can be stored for peaking operation. In this way, the plant operates with built-in subsidies. In a second variation of this system, the fuel could be hydrogen, CO_2 being removed from the gas. CO_2 is a valuable chemical for enhanced oil recovery, and can be piped to oilfields at a cost of about $0.08 - 0.16/MSCF (equal to $0.18 - $0.40 per million Btu of hydrogen) per hundred miles of pipeline distance [10]. The selling price of the CO_2 can be up to $5.60 per million Btu of hydrogen at the oilfield [2, 6]. Further details are given in Ref. 2. The ultimate result is that both the hydrogen and the electricity are highly subsidized and will be relatively inexpensive.

The above concept, using domestic coal and coproduced hydrogen, electricity and CO_2, all subsidizing each other, can provide an enormous chance for the U. S. to develop hydrogen production and utilization technology in advance of Germany and Japan, presently front-runners in hydrogen research, but who lack the great U. S. fossil energy resource in the form of coal. This development will have great export potential and represents an "insurance policy" for future generations. The U. S. Government, via the fossil division of the Department of Energy, should strongly back this coal-hydrogen energy route, which will provide the basis for a future hydrogen economy, first in regions with high NO_x and hydrocarbon pollution such as Southern California, as Rep. George Brown will recognize.

The coal-hydrogen-electricity installations will be subsidized by the need for CO_2 for tertiary oil recovery. Later, when the oil runs out and CO_2 requirements for this application diminish, perhaps towards the year 2015, the "grenhouse effect" can be totally avoided by burying the CO_2 in capped empty oil or gas wells at little extra cost to the national energy system as a whole. Enough empty permian strata with the right qualities exist in the U. S. to serve as a permanent innocuous depository until well into the 21st century. If necessary, the deep oceans can also eventually be used as a CO_2 burial ground. Pressurized liquid CO_2 can be injected into the deep oceans, where it will first form a stable layer and eventually a hydrate. Ultimately, it will end up as carbonate, completing the natural CO_2 cycle much more rapidly than would have been the case if the natural flux between the atmosphere and the oceans had been relied on. In fact, if all the earth's natural fossil resources were converted into CO_2 and then disposed of in the oceans, the concentration of CO_2 would only rise by a miniscule amount, about one part per million by weight. This tiny concentration change, which would have absolutely no natural effects, simply shows the immensity of the oceans as a CO_2 sink.

Finally, the discovery of the new "hot" superconductors opens new vistas for the coproduction of hydrogen and electricity, first during the period where it is economically necessary to manufacture electricity and hydrogen from coal, and then when this technology is eventually overtaken by solar hydrogen/electricity. Superconductivity by materials such as polycrystalline thin-film barium-doped yttrium or rare-earth copper oxide perovskites at temperatures of 77K (liquid nitrogen) or higher, while remarkable, is not necessarily very practical, since experiments show that the sustainable superconducting maximum current density (amperes per square cm of cross-section) is quite small compared with that of classical liquid helium superconductors. However, the values increase by orders of magnitude as the conductor is further cooled, thus correspondingly reducing the cost of the cable. If liquid hydrogen is coproduced with electricity, it can serve as a refrigerant and can be tapped off where needed as a fuel, thus serving a dual purpose and reducing the cost of the superconducting cable substantially. The necessary fuel (for transportation and other uses, using advanced high-efficiency fuel cells) and electricity for on-site use will thereby subsidize each other in the most economic manner. In summary, the U. S. cannot afford to ignore the potentialities of the above exciting prospects, and should strongly support studies and research on hydrogen derived from coal and solar energy, and on its storage and end-use, particularly with fuel cells, including those for transportation.

Thank you.

Addendum. Testimony before House Subcommittee on Energy Research and Technology, dated July 9, 1987 (for information only, not part of record).

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Senator MATSUNAGA. Thank you, Dr. Appleby.

We would like to hear now from that great Director of the Hawaii Natural Energy Institute, a former staff member of mine, Dr. Patrick Takahashi.

STATEMENT OF DR. PATRICK K. TAKAHASHI, DIRECTOR, HAWAII NATURAL ENERGY INSTITUTE

Dr. TAKAHASHI. Thank you, Senator Matsunaga. It is nice to be back in this room. It seemed like I spent a good portion of my adult life listening to statements like this a few years ago.

Let me enter the full statement for the record. I will focus on two or three things which have not been mentioned in any great detail. Everything else in our statement has been mentioned already.

I might add that this testimony was prepared jointly with Dr. David Block, who is the Director of the Florida Solar Energy Center. And he was sitting in the audience until a few minutes ago, but had to go on to another meeting.

Senator FORD. Your written statement will appear in full in the record.

Dr. TAKAHASHI. Thank you very much.

Dr. Block's institute and the Hawaii Natural Energy Institute completed for the Department of Energy earlier this year a technology status assessment of hydrogen from renewable energy. And one of the questions asked earlier was what are the priorities in research, and in this report—it's a full volume treatise—we, after scouring the country and incorporating the views of much of the world, presented a series of research priorities. I would like to send in to this committee the full report for your files. You can use portions for the record as you can see fit.

This report very quickly emphasized that where biomass is plentiful, gasification offers the earliest economical route to producing hydrogen, as well as methanol.

Two, research on photovoltaics will enhance the already considerable attractiveness of electrolyzing water which produces very pure hydrogen, as well as useful oxygen.

Three, direct conversion of solar energy through photo processes—and these are photobiological, photoelectrochemical, and hybrid concepts—is an area of long-term research and should receive a substantial level of support.

Four, significant demand for hydrogen can be expected to develop in parallel with increased space vehicle launch activity and with development of transatmospheric vehicles after the mid-1990s. I might add as an aside that if Hawaii becomes an international space port center, the hydrogen will have to be produced locally. And the only real option we have is to use our indigenous renewable options.

Finally, five, research to develop commercial applications must be conducted in parallel with hydrogen production innovations.

So, the report can be boiled down to these high priority research areas.

I might note a second point that if you consider all of the research conducted by the Department of Energy and my institute, for example, since 1973, almost all of the technologies seem to involve electricity, whether it is OTEC, wind power, geothermal, photovoltaics. You can go right down the line.

Our energy problem is much more closely related to transportation fuel. And over the past few years in Hawaii, we have begun to focus a lot more on the medium term for methanol and the longer term for hydrogen. And these bills that are before this committee are excellent to shift some of the focus to look at what is our real problem. In 1973 and in 1979 these were transportation fuel crises. In the future we can expect the same thing. And David Block and I endorse the three of your bills. And certainly in the case of S. 1296, it is the only real alternative to a future aviation economy.

Finally, the various hydrogen bills that you have been introducing have been around for 6, 8, maybe 10 years now. And it gets so far, and it doesn't quite make it. Today it is sort of an extraordinary one in the sense that both the House and the Senate are hearing the same bill. And the support in the House was very strong. I would hope that the Senate support is similarly strong, and I would like to highly encourage the Congress to pass a bill such as this that can send a signal to the Department of Energy—really to the White House—that this is, indeed, a point of great concern.

Many people tend to blame the Department of Energy for being somewhat slow in reacting to this area, but I would suspicion that the lack of motivation really derives from outside the Department of Energy. And I think a bill of this sort can go a long ways into improving our national security over time.

Another matter that has come up as a negative factor of the bill perhaps is that $200 million seems like a whole lot of money. Spread out over five years, taking a page from your analogy, Senator Matsunaga, if the Nation were to build only 99 F-14s, F-15s or F-16s, as opposed to 100, just one less, that money can be used to support this $200 million program that is written up in your bills.

So, in a nutshell we are very supportive of the three bills. We would very highly encourage the Congress to make them into law.

Thank you.

[The prepared statement of Dr. Takahashi follows:]

TESTIMONY ON S. 1296: TO ESTABLISH A HYDROGEN RESEARCH AND DEVELOPMENT PROGRAM

by

David L. Block, Director
Florida Solar Energy Center
300 State Road 401
Cape Canaveral, Florida 32920

and

Patrick K. Takahashi, Director
Hawaii Natural Energy Institute
2540 Dole Street
Honolulu, Hawaii 96822

given before

U.S. Senate
Subcommittee on Energy Research and Development
Committee on Energy and Natural Resources

September 23, 1987

Dr. David Block and I very enthusiastically support your bill to establish a more coherent and expanded hydrogen R&D program. We want to begin by thanking the subcommittee for this opportunity to state our views on the use of hydrogen energy and on the possibilities for producing hydrogen from renewable resources. Our comments today will point out that hydrogen has real potential to fuel our nation's energy future.

I. Potential of Hydrogen

Hydrogen may well be the best energy option for sustaining and supporting human society. It is the ideal replacement for fossil fuels, the most abundant element in the Universe, can be produced from renewable resources, and does not pollute the environment. Hydrogen is also an important feedstock for the production of various synfuels, including methanol.

In the past few years, national attention on hydrogen has increased for several reasons:

- NASA is rebuilding the space shuttle program, which remains the world's largest consumer of hydrogen.

- The Department of Defense has begun to develop transatmospheric military vehicles that, because of certain technical performance advantages, could be powered by hydrogen. In any case, expanded space program requirements perhaps at future island sites, will require indigenous production of hydrogen.

- The national and international scientific communities have raised well-founded alarms about acid rain and the "greenhouse effect," both of which will be alleviated by use of hydrogen rather than fossil-based energy forms.

- Alternative fuels production processes can be developed to maximize the energy stored in the available carbon substrate and minimize the discharge of CO_2 to the atmosphere. The development of a renewable hydrogen production technology will have major beneficial impacts on all alternative fuels production scenarios.

- In the transportation sector -- the largest consumer of oil -- hydrogen offers a clean alternative and the fuel choice of the future.

- World oil supply locations and shipments have raised concerns about national security, which point to the importance of indigenous energy resources such as hydrogen. We won't be blackmailed by any capricious Middle East potentate if we can produce our own energy needs.

While these points are only fuzzily defined in our own national consciousness, they are quickly crystallizing in the collective thinking of other governments. R&D on hydrogen energy is a classic example of a technological area where the U.S. is again watching its once firmly anchored position of leadership drift overseas.

II. National and International Hydrogen Programs

At a March conference on hydrogen energy, Germany's State Economy Minister Martin Herzog delivered the welcoming address, in which he officially announced his government's intention to create a new center for solar and hydrogen energy research in Stuttgart, West Germany. He told the audience of international scientists that the center's purpose will be to "assure a base for medium- and long-term R&D in the area of regenerative energy." Further, Herzog announced, the center will initially receive seed funding of $6 million to ensure that it becomes "a crystallization point" for solar and hydrogen energy research.

It's obvious that Germany is willing to expend considerable financial resources to ensure development of indigenous, renewable energy resources. There can be no doubt that this German initiative was spurred, in part, by the nuclear accident at Chernobyl. There can also be no doubt that Germany intends this initiative to result in a university-centered "Hydrogen Valley" at Stuttgart much like our own "Silicon Valley" in California.

The German hydrogen energy initiative illustrates how easily the U.S. ignores the very lesson it taught the rest of the world so well: define a problem, reconstruct it as an opportunity, and act on it.

The Japanese have also given us an example of how this lesson can be applied. While U.S. efforts are directed toward retrofit of diesel engines to use hydrogen fuel, Japan virtually leap-frogged the problem by designing a new combustion chamber and valving process specifically for hydrogen fuel.

The U.S. must commit to its own hydrogen energy initiative with the consistent, sustained support necessary for a productive, long-term R&D effort. This is, after all, the role the federal government fills in energy R&D -- addressing high-potential technologies faced with high investment risks. Hydrogen production is just such a high-potential technology option.

The hydrogen question that must be answered immediately is this: which technology for hydrogen production will evolve as the best commercial option, and in what time frame? Only a substantial R&D effort will reveal the answer.

III. State Projects and Congressional Initiative

The states of Florida and Hawaii have already begun to address the hydrogen question. Convinced of hydrogen energy's potential, our states have undertaken a joint R&D program, initially supported by state funds. But Congress has recognized that two states alone cannot uncover the hydrogen solution, especially given their limited funding potential. Your bill to upgrade the national hydrogen program can be the solution to our long-term energy problem.

The United States' current program began through Congressional initiative in 1985, when the Department of Energy commissioned our Florida and Hawaii institutes to assess the status of hydrogen technology and to determine research priorities. The broader objective was to launch a vigorous research program that would put hydrogen energy to commercial use in the shortest possible time frame.

The Florida Solar Energy Center and Hawaii Natural Energy Institute reported in December 1986 the following conclusions on the state of the technology:

1. Where biomass is plentiful, gasification offers the earliest economical route to producing hydrogen as well as methanol and ammonia.

2. Research on photovoltaics will enhance the already considerable attractiveness of electrolyzing water, which produces very pure hydrogen as well as useful oxygen.

3. Direct conversion of solar energy through photoprocesses is an area of long-term research and should receive a substantial level of support.

4. Significant demand for hydrogen can be expected to develop in parallel with increased space vehicle launch activity and with development of transatmospheric vehicles after the mid-1990s.

5. Research to develop commercial applications must be conducted in parallel with hydrogen production innovations.

Congress provided $1.2 million in this fiscal year to follow-up on these research priorities. Our research institutes are working closely with the Solar Energy Research Institute on this continuing program. The House appropriations process doubled the budget to $2.4 million for fiscal '88. The Senate is appearing to recommend level funding. A far more vigorous national effort is recommended, which is provided for in your bill.

IV. Future Hydrogen Program

Given Congressional support, DOD interest, NASA reconstruction, DOE direction, SERI and other national laboratory leadership, and expansion of the program initiated by the Florida/Hawaii team, our country can regain control over our energy future.

As currently outlined, the first-year national R&D program will address the promising alternatives delineated in the Florida/Hawaii study. Florida will take the lead in investigating power applications, while Hawaii will assume responsibility for research on renewable fuels. Expansion of research activities is anticipated with increased funding in fiscal year 1988.

The focus of our work will not shift; it will remain targeted on hydrogen production areas that show the greatest promise for cost-effective commercialization. General priority issues that must be addressed by research include total systems analysis of processes and economics, development of continuous processes, and engineering analysis to determine fundamental limits of performance and production processes.

With respect to the photo-production processes, research in the photoelectrochemical area must identify new electrode materials and catalysts, determine system stability, and solve photo-corrosion and regeneration issues. In the photobiological area, research must address issues of system stability, production in aerobic and marine environments, genetic engineering innovations and system analyses. Both whole cell and cell free systems can ultimately produce hydrogen efficiencies up to 25%, which are significantly greater than other bioconversion processes. Photoelectrolysis has an even higher theoretical limit and needs to be investigated.

We recommend, further, that the best minds from throughout the world be asked to form a network to share ideas and together attempt to engineer technical breakthroughs. The Pacific International Center for High Technology Research has initiated such a program.

Finally, it is very highly recommended for the Department of Energy to work closer with the Department of Defense and NASA to assure for a more competitive hydrogen fuel source in the future. A few percent of the expenditure for the National Aerospace Plane should be set aside for hydrogen production R&D.

V. Conclusion

We continue to fear that the federal government's attitude and energy policies are counterproductive to our national well being. During the past few years of reprieve, we have virtually eliminated alternative transportation fuels development, reduced the renewable energy R&D budget by an order of magnitude, and increased our importation of oil to the 1973 level. Chevron USA only this past month reported that the United States will be importing more oil in the year 2000 than we are today....with the warning that much of this supply to our country and allies will need to come from the Middle East. Common sense screams for the need to develop alternatives to imported oil. Your Committee has the demonstrated leadership necessary to bring sense and order to our national energy program. We urge you to take another giant step toward ensuring the nation's energy future by placing major emphasis on hydrogen energy from renewable resources.

Senator MATSUNAGA. Thank you very much, Dr. Takahashi. We would be happy now to hear from you, Dr. Veziroglu.

STATEMENT OF DR. T. NEJAT VEZIROGLU, PRESIDENT, INTERNATIONAL ASSOCIATION FOR HYDROGEN ENERGY AND DIRECTOR, CLEAN ENERGY RESEARCH INSTITUTE, UNIVERSITY OF MIAMI

Dr. VEZIROGLU. Thank you, Mr. Chairman, and the staff of the committee.

We at the Clean Energy Research Institute of the University of Miami and the International Association for Hydrogen Energy strongly support all the three bills. They are the right step for the introduction of the universal, clean hydrogen energy system which is inevitable.

Now, we have given our written statement. I understand it will be in the committee records. So, therefore, I will only concentrate in the conclusions of our statement. But before getting into that, I would like to mention some of the exceptions I am taking to Ms. Fitzpatrick's statements, which are not correct scientifically—which are not correct.

She mentioned that you need 4 to 15 times more energy to produce hydrogen. Now, for example, if you produce hydrogen from hydropower, you can convert 80 percent of the energy in it to hydrogen. If you produce hydrogen from coal, you can convert 65 percent of it to hydrogen. From solar energy today technology is available for production of 10 percent of the solar energy to hydrogen, the same as the electricity. But in the laboratories, 20 to 25 percent efficiencies have been obtained.

Coming back to our conclusions, now, the hydrogen in that system will reduce pollution, carbon dioxide emission and acid rains and, hence, the environmental damage; provide a permanent energy infrastructure based on a clean, efficient and economical carrier, hydrogen; provide the aerospace sector with the best possible fuel; eliminate the United States dependence on imported oil; eliminate or reduce the trade deficit; provide new jobs for establishing and servicing the new energy system; make the United States a leader in future energy technology; assure low cost fossil fuel supplies to be available for non-energy applications, such as fertilizers, synthetic fibers, lubricants.

Now, when its utilization efficiency and environmental compatibility are taken into account, hydrogen becomes the cheapest fuel. Again, this is contrary to Mrs. Fitzpatrick's statement.

And this calculation, which I presented to the committee, does not take into account the cost of military operations in the Persian Gulf. If those costs are added to the side of the petroleum, then hydrogen becomes much, much, much cheaper.

Now, the United States has large deposits of coal. And during the changeover period from fossil fuels to hydrogen, they could be used for the production of hydrogen. For example, near the coal mines, hydrogen could be produced. In Alaska there is a large potential of hydropower. There hydrogen could be produced using hydropower. And these will both result in low cost hydrogen with the present technology. And this hydrogen could be transported by pipelines to consumption centers and utilized in the space programs, fuel cells and other devices.

Now, the above approach will result in many economical and environmental benefits. The cost of energy transportation will be much lower than transporting coal in the case of coal hydrogen, and much lower than transporting electric power transmission in the case of hydropower hydrogen.

Also, it would be much easier to contain the pollutants in a large central plant, coal hydrogen producing plants, as mentioned earlier by Dr. Appleby. For example, CO_2 produced could be used for the in-house production of petroleum.

According to our calculations at the University of Miami, environmental damage resulting from the combustion of fossil fuels has reached staggering proportions. In the United States it is now $400 billion per year and is growing. Last year the United States-Canada Commission recommended that the two countries spend $5 billion over the next five years to reduce SO_2 emission from coal burning plants by 50 percent.

These remedies will not solve the problem but will only delay the consequences. First of all acid rains are not produced by SO_2 alone. Emissions, such as CO_2, the main combustion product of fossil fuels, also produce acids. And there is no way to reduce CO_2 if we burn fossil fuels. Even if halving the SO_2 emission could reduce the acid rains by 50 percent, it would only double the time it would take to destroy lakes and forests in particular and our biosphere in general.

However, there is a permanent solution. If we use hydrogen in place of fossil fuels in our power plants, industry, transportation and homes, there would be no pollution and acid rains. And as a bonus, we would also get rid of another environmental hazard caused by fossil fuels, the greenhouse effect. It is a clean and efficient fuel.

Initially the hydrogen needed could be produced from coal and hydropower. And eventually the solar hydrogen will replace the coal hydrogen. Hydrogen could also be produced by wind power, geothermal energy, and even by nuclear energy.

The space program runs on hydrogen. There are fuel cells, cars, buses and homes running on hydrogen. Presently it is not being used on a large scale because its production costs are in general higher than those of fossil fuels. However, our studies show that if the cost of environmental damage and the higher efficiency of hydrogen are included in comparisons, then hydrogen becomes cheaper.

The Federal Government should not be spending money on halfway solutions, such as spending $5 billion for reducing SO_2 emission by 50 percent, but should concentrate on permanent solutions. They should use those funds on research for the production and utilization of hydrogen to replace the fossil fuels. This would help solve the interrelated global problems of our times, the energy and environmental problems, and does lay the foundations for a clean and permanent energy system, the hydrogen energy system.

We would like to urge the Congress to make the policy of the United States to convert from the present fossil fuel system to the clean and renewable hydrogen energy system in a planned way to be completed over the next 50 to 60 years to coincide with the anticipated depletion of petroleum and natural gas. Japan, the Soviet Union and the Europeans are working on this concept. We must not be the followers, but take the lead.

Now, in conclusion, I would like to mention a related subject, as mentioned by Dr. Appleby earlier, that we would like to request that in the House version of the energy and water development appropriation bill, H.R. 2700, be included an item for $2.4 million to support hydrogen research in the four institutions around the country. In the Senate version the item was reduced to $1.2 million, and the Clean Energy Research Institute and the Texas A&M Hydrogen Energy Research Institute were left out of the bill. We would like to request that, being the leading hydrogen energy research institutes in the United States and perhaps in the world, the support for these institutes in addition to others, the Hawaii Natural Energy Research Institute and Florida Energy Center, be included in the Senate bill as well.

Thank you.

[The prepared statement of Dr. Veziroglu follows:]

STATEMENT IN SUPPORT OF S.1294, S.1295 & S.1296 HYDROGEN FUEL CELL RESEARCH, HYDROGEN FUEL CELL UTILIZATION AND HYDROGEN RESEARCH & DEVELOPMENT BILLS

T. Nejat Veziroglu
President, International Association for Hydrogen Energy
Director, Clean Energy Research Institute
University of Miami
Coral Gables, Florida 33124

A. Energy/Environmental issues Facing U.S.A.:

1. Fossil fuels (Petroleum, natural gas and coal), which meet most of the energy needs today, are finite in amount and will eventually be depleted, with the decrease in production expected to start at the end of this century or the early part of the next century (see Fig. 1).

2. The combustion products of fossil fuels are causing in-creasing damage to our Biosphere (the only known domain in the universe to be supportive of life), and especially to its living components, through pollution, acid rain, CO_2 emission and carcinogens. Our studies at the University of Miami indicate that this damage in 1986 was $8.26 per GJ of fossil energy consumed (see Table I).

3. For about one-half of its petroleum requirements, the U.S. depends on imported oil, mostly from unstable regions of the world. This is also the number one culprit for the large trade deficit.

4. There exists a need for a high energy content and low weight fuel to satisfy the requirements of the growing and important space programs (e.g., rockets, shuttle, aerospace planes).

B. U.S.A. Non-Fossil Energy Resources:

1. The United States possesses large non-fossil energy resources, such as nuclear, direct solar, hydro, wind and geothermal, all of which can be converted to heat and/or electricity with the existing technology.

2. These energy sources are much cleaner than fossil fuels, and will last much longer. Some of them are renewable (solar, hydro, wind), and others could meet the demand for several decades (nuclear fission).

3. However, these energy resources have some shortcomings. Some of them are intermittently available (e.g., solar, wind); others are available too far away from the consumption centers (e.g., Alaskan hydro potential); and it would be better to locate nuclear power plants away from the population centers in order to diminish potential damage from accidental release of radioactivity.

C. <u>Requirements for an Energy Carrier (Synthetic Fuel):</u>

The shortcomings of the renewable energy resources point out the need for an intermediary energy system (or an energy carrier) to form the link between the non-fossil energy resources and the user. The intermediary system must satisfy the following criteria:

1. It must be storable.

2. It must be transportable.

3. It must be fuel for transportation.

4. It must be efficient.

5. It must be environmentally compatible.

6. It must be economical.

7. It must be recyclable, if possible.

D. <u>Hydrogen Energy System:</u>

All the synthetic fuels are candidates for the intermediary system. Amongst them, hydrogen meets the above stated criteria better than any other, as stated herebelow:

1. It is storable and transportable.

2. It is recyclable.

3. It is environmentally the most compatible fuel.

4. It is the lightest fuel - three times lighter than petroleum or natural gas for a given amount of energy. Hence, it is the ideal fuel for the aerospace programs.

5. Hydrogen is the most efficient fuel. It can be converted to electricity, mechanical power and heat more efficiently than fossil fuels or other synthetic fuels. (See Table II).

6. When its high utilization efficiency and environmental compatibility are taken into account, hydrogen becomes the cheapest fuel (see Table III).

E. Benefits of the Hydrogen Energy System:

1. Reduce pollution, CO_2 emission and acid rains, and hence environmental damage.

2. Provide a permanent energy infrastructure based on a clean, efficient and economical energy carrier, H_2.

3. Provide the aerospace sector with the best possible fuel.

4. Eliminate U.S. dependence on imported oil.

5. Eliminate or reduce the trade deficit.

6. Provide new jobs for establishing and servicing the new energy system.

7. Make the United States a leader in future energy technology.

8. Assure low cost fossil fuel supplies to be available for non-energy applications (e.g., fertilizers, synthetic fibers, lubricants).

F. Changeover Period:

The United States possesses large deposits of coal - much more than fluid fossil fuels (i.e., petroleum and natural gas). Also, it so happens that from the production cost point of view, the cheapest hydrogen can be produced from coal (See Table III). Coal produced hydrogen is even cheaper than coal produced S.N.G. When the effective costs are compared, coal produced hydrogen effective cost is very close (within 3%) to that of hydropower hydrogen.

In addition to having large deposits of coal, the United States also has a large potential of hydropower in Alaska.

It then becomes prudent to do the following during the changeover period:

1. Produce hydrogen from coal near the coal mines.

2. Produce hydrogen from hydrogen near the hydroelectric power sources.

3. Transport energy as hydrogen by pipelines to consumption centers.

4. Utilize hydrogen in space program, fuel cells and other devices.

The above stated approach would result in many economical and environmental benefits: The cost of energy transportation will be much lower than transporting coal in the case of coal hydrogen, and much lower than electric power transmission in the case of hydropower hydrogen. Also, it would be much easier to contain the pollutants in large central plants (coal hydrogen producing plants) than several smaller plants (factories, thermal power plants, etc.).

G. What other Countries are Doing:

1. The Soviet Union has an annual conference on Hydrogen Energy. We are told that it is attended by 1,000 scientists and engineers from U.S.S.R. and other socialist countries. A similar conference in the United States draws 300 to 500 participants.

2. Canada spends $20,000,000 a year on hydrogen energy research, which is about the same as the present DoE budget on hydrogen. On a per capita basis, the Canadian effort is ten times greater than that of the United States.

3. Japan and the E.E.C. also have large hydrogen energy projects. We do not have the figures; however, we believe their per capita effort is more in line with that of Canada than the United States.

H. Recommendation for Funding:

Environmental damage resulting from the combustion of fossil fuel has reached staggering proportions. In the United States, it it is now 400 billion dollars per year and is growing. Last year the U.S.-Canada Commission recommended that the two countries spend $5,000,000,000 over the next five years to reduce SO_2 emission from coal burning plants by 50 percent. These remedies will not solve the problem, but will only delay the consequences. First of all, acid rains are not produced by SO_2 emissions alone; CO_2, the main combustion product of fossil fuels, is also a culprit, and there is no way to reduce it if we burn fossil fuels. Even if halving the SO_2 emissions could reduce the acid rains by 50 percent, it would only double the time it would take to destroy the lakes and forests in particular, and our Biosphere in general.

However, there is a permanent solution. If we use hydrogen in place of fossil fuels in our power plants, industry, transportation and homes, there would be no pollution and acid rains; and as a bonus, we would also get rid of another environmental hazard caused by fossil fuels: the greenhouse effect. It is a clean and efficient fuel. Initially, the hydrogen needed could be produced from coal and hydropower, and eventually solar hydrogen would replace the coal hydrogen. Hydrogen could also be produced by wind power, geothermal power, and even by nuclear energy.

The space program runs on hydrogen. There are fuel cells, cars, buses and homes running on hydrogen. Presently, it is not being used on a large scale, because its production costs are in general higher than those of fossil fuels. However, our studies at the University of Miami show that if the cost of environmental damage and the higher efficiency of hydrogen are included in comparisons, then hydrogen becomes cheaper.

The Federal Government should not be spending money on half-way solutions, but should concentrate on permanent solutions. They should use those funds on research for the production and utilization of hydrogen to replace the fossil fuels. This would help solve the interrelated global problems of our times, the energy and environmental problems, and thus lay the foundations for a clean and permanent energy system--the Hydrogen Energy System.

We would like to urge the Congress to make it the policy of the United States to convert from the present fossil fuel system to the clean and renewable Hydrogen Energy System in a planned way to be completed over the next 50-60 years - to coincide with the anticipated depletion of petroleum and natural gas. Japan, the Soviet Union and the Europeans are working on this concept. We must not be the followers, but take the lead.

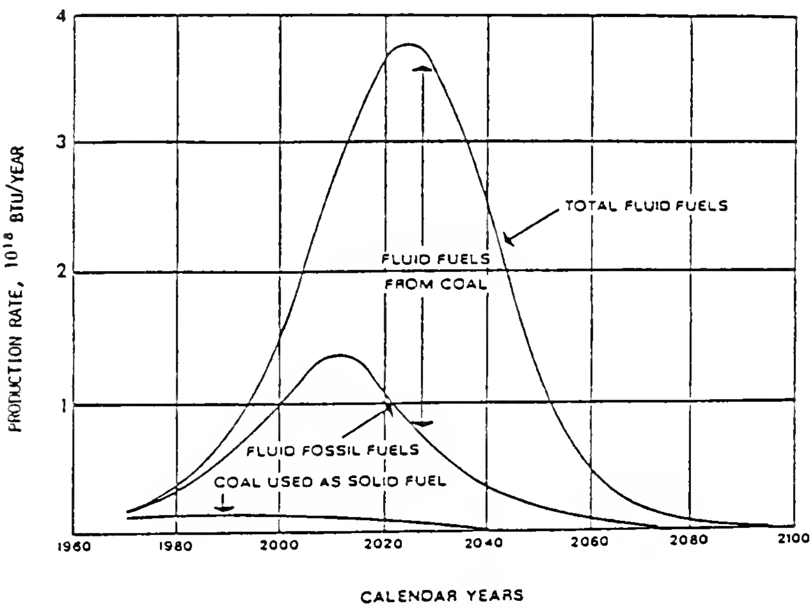

Fig. 1 Projected rates of production of world fossil fuels.

Table I. Estimates of fossil-fuel damage

	Type of damage	References	Damage per unit of fossil-fuel energy (1986 $ GJ^{-1})
1	Effect on humans (loss of working time, medical expenses, deaths)	[86–88]	3.86
2.	Effect on fresh water resources/sources (loss of fish, damage to drinking water)	[22, 89]	1.93
3.	Treatment of lakes (treatment by powdered lime)	[11]	0.06
4	Effect on farm produce, plants and forests (acid rains, ozone)	[15, 21, 89]	0.57
5	Effect on animals (domesticated or wildlife)	[89]	0.49
6.	Effect on buildings (historical, commercial and residential)	[18]	0.83
7	Effect on coasts and beaches (oil-spills, ballast discharge)	[12]	0.09
8.	Effect of ocean rise (coastal protection)	[89]	0.31
9	Effect of strip-mining (land reclamation)	[28]	0.12
	Total damage:		1986 $8.26

Table II Utilization efficiency comparison between fossil fuels and hydrogen

Energy sector	Fossil energy consumption by sector (Arbitrary units)	End-use energy form/ sub-sector	Fossil energy consumption by end-use (Arbitrary units)	H_2 efficiency advantage $100(\eta_s-\eta_f)/\eta_f$ (Percentage)	Reference	H_2 energy consumption by end-use (Arbitrary units)	H_2 energy consumption by sector (Arbitrary units)
Transport	250	Road (IC engine)	120	22	[81]	99	186
		Road (fuel cell)	25	133	[60]	11	
		Rail (fuel cell)	15	84	[60]	8	
		Sea (IC engine)	25	22	[81]	21	
		Sea (fuel cell)	15	84	[60]	8	
		Air (subsonic)	25	19	[76]	21	
		Air (supersonic)	25	38	[77]	18	
Industrial	300	Heat	250	24	[83]	145	210
		Electricity (fuel cells)	50	84	[60]	65	
Commercial	150	Heat	110	24	[83]	89	111
		Electricity (fuel cells)	40	84	[60]	22	
Residential	300	Heat	250	24	[83]	202	229
		Electricity (fuel cells)	50	84	[60]	27	
World totals.	1000						736

Table III Effective cost of synthetic fuels

Fuel		Production cost (1986 $ GJ^{-1})	Environmental damage (1986 $ GJ^{-1})	Utilization efficiency ratio η_f/η_s	Effective cost (1986 $ GJ^{-1})
SNG		7.42	5.51	1.00	12.93
GH_2	Coal	7.19	2.75	0.74	7.36
	Hydropower	9.65	—	0.74	7.14
	Other	18.13	—	0.74	13.42
SynGas		14.47	8.26	1.00	22.73
LH_2	Coal	8.99	2.75	0.74	8.69
	Hydropower	12.06	—	0.74	8.92
	Other	22.66	—	0.74	16.77

Senator FORD. Thank you very much, gentlemen. I have no questions of any of the three.

Senator Matsunaga, do you have any questions?

Senator MATSUNAGA. I just wish to commend all three witnesses for their excellent presentations, and as the introducer of the bills, I certainly appreciate the support that you have shown not only today, but in the past.

And with all the strong points you have raised, Dr. Appleby, for example, I often wonder why the coal state Senators aren't cosponsoring my bill. And with that remark, I would say thank you again.

Senator FORD. And I say to you, Senator, we have got more on our plate than we can say grace over, if you understand that.

Thank you, gentlemen.

The next panel of witnesses, the Vice President for Research, Solar Reactor Technologies, Dr. Peter Langhoff; Chief, Combustion Analysis and Technology, Pratt & Whitney, Mr. Richard Marshall.

Gentlemen, I don't mean to cut you off. The last panel was a little bit long. If you could highlight your statements, your full statement will be included in the record. And we will let Mr. Langhoff—is that the way it is pronounced?

Mr. LANGHOFF. That's correct, sir.

Senator FORD. Close for a southern boy.

STATEMENT OF DR. PETER W. LANGHOFF, VICE PRESIDENT FOR RESEARCH AND DEVELOPMENT, SOLAR REACTOR TECHNOLOGIES, INC., ACCOMPANIED BY ROBIN Z. PARKER, PRESIDENT

Dr. LANGHOFF. Mr. Chairman, Senator, ladies and gentlemen, we are pleased to provide testimony on behalf of these three bills with particular reference to S. 1296.

We speak from the perspective of the small business, high technology research and development community, and a community long-regarded, I believe correctly, as an objective source of innovative technology. We follow very closely the science developments in energy and we try to move that science forward into technology. And yet, at the same time we are not wed to any particular processes or feed-stream materials.

I am going to ask that a statement on behalf of our chairman, Mr. Robin Parker, who sits to my left, be submitted for the record. It's an introductory statement.

Senator FORD. It will be included in the record in total.

Dr. LANGHOFF. Thank you, sir.

Senator FORD. Let me ask the Clerk. Do you have a copy of that? Okay, fine.

Dr. LANGHOFF. And similarly for my technical remarks.

Senator FORD. They will be included in the record in full.

Dr. LANGHOFF. Thank you, sir.

This bill recognizes correctly that continued research and development of hydrogen fuel technology as a viable alternative to the combustion of our rapidly depleting fossil fuel reserves is of vital importance to the Nation's economy and our environmental wellbeing.

I am going to emphasize in my remarks here the urgency and the immediacy of this possibility, and I am going to indicate that a number of factors augur very well for the development of efficient, large scale hydrogen production facilities consequent of sufficient funding levels for this purpose.

These factors are simply that, one, water, the very product of combustion is plentiful and widely available as a feed-stream material.

There are now a great variety of chemical and physical processes involving hydrogen release that have been studied to date under laboratory conditions with extremely promising efficiencies. This is the type of research that the Department of Energy has sponsored through the years, and we applaud them in that connection.

And finally, three, solar energy devices presently under development, some of which are in existence right now, provide environmentally satisfactory energy for driving the release of hydrogen.

It is on this score that the Department of Energy and I differ. Our company differs. We do not at present in our view have an appropriate program for bringing to the fore solar energy as the driving force for hydrogen technology.

And I am going to now make one or two extemporaneous remarks in response to some of the discussion that has taken place here with your kind permission, and then I'll close by describing very briefly one or two aspects of the things that SRT as an individual company has been involved in. Again, I present these as representative of the small business community.

I would first draw attention to the use of the word "primary" in connection with energy and fuel. There is only one primary energy source and that is solar energy. All other energy sources ultimately derive from that source, as the Assistant Secretary and enlightened members of the committee and the panel certainly know.

I am very pleased to see the Secretary cite the energy efficiency factors ranging from 4 to 15 percent. These relate to energy of conversion efficiencies of 25 percent to 75 percent or so.

I'll describe very briefly in a moment a system that can turn solar photons, solar energy, directly into hydrogen or into electricity running at the 25 percent level. This technology is here today. It is being developed by our company and other companies as well. We are presently under contract to the Air Force to provide 50 kilowatts of space power to a station that will operate only with solar photons. It gets very expensive to bring the methane that some people regard as very cost efficient. It gets very expensive to bring that fuel to near space. Solar photons are certainly available there.

The earth is very much in a similar situation. It only takes a little bit of thought to realize that.

The main objection I have to the DOE present funding level is the scope. And I think this bill starts to move in the right direction.

If we were to replace all our energy usage today with hydrogen, if that could be possible, this would take an increase in our current hydrogen production of about a factor of 2,000. This is a significant order of magnitude. These figures are based on some numbers I was calculating while listening to the very enlightening testimony that has gone before. It would take, if you wanted to make that much hydrogen, to derive hydrogen of 2,000 times what we are producing now, we would have to have a cubic mile of water release its hydrogen to us. This is the scope of the problem that we have in mind here.

These things, however, are possible when one recognizes that at a 25 percent efficiency you would only need the sunlight falling of the area the size of Long Island running out from Manhattan Island a few hundred square miles. And even if we needed 500 square miles, since solar photoenergy comes down to us continually during an eight hour period in many parts of the country, a 25 percent conversion factor is an extremely efficient, extremely useful and a beneficial operating factor.

And so now let me describe very briefly, having made those—let me make one last remark. The word "cost" has been used here. There is a significant difference between price and cost, and this bill has a provision for setting up a technical advisory panel. That panel is well advised itself to distinguish very carefully between cost and price. And I am sure the people appointed to that panel will be quite able to do so.

And now, in conclusion—I have taken perhaps much more of your time than is necessary—let me simply describe very briefly a system that we have devised recently that is presently under development by our company SRT, which employs water as a feedstream material, electrolysis and photochemistry, coming from the type of research that DOE has supported through the years. And we applaud them in that effort. This provides the essential hydrogen release process. And third, our process employs sunlight only as the driving force to run photolysis and to provide the electricity needed to do the electrolysis.

This system deals with splitting not of water, but of hydrogen chloride which is prepared in aqueous form. I won't go into all the details, the technology here. There are technical advantages for the electrolysis of hydrochloric acid as opposed to other commercially available procedures. We have worked long and hard to maximize the efficiency of this process.

The hydrogen is captured from this release process. The chlorine gas that is captured is recycled back to make more hydrochloric acid. And the cycle then continues. The electrical energy put into this system derives from the type of system that I indicated earlier in which electricity is made directly out of solar energy using the technologies that SRT has devised.

These two systems that we have been working on are only two examples of a number of systems that have been devised in the small business community and elsewhere. And in view of the efficiencies that are now available, we consequently support and applaud the allocation of resources for the development of an efficient and environmentally satisfactory thermal energy source in the form of a national hydrogen fuel technology.

Thank you very much for your attention.

[The prepared statements of Mr. Parker and Dr. Langhoff follow:]

SOLAR REACTOR TECHNOLOGIES
2666 Tigertail Avenue • Suite 115 • Miami, FL 33133
(305) 854 2668 • FAX (305) 854 2739

INTRODUCTION TO TESTIMONY ON
PHOTOELECTROCHEMICAL TECHNOLOGY FOR HYDROGEN
PRODUCTION CONCERNING BILLS S.1294, S.1295, S.1296
23rd September 1987

Mr. Chairman, Senators, Ladies and Gentlemen:

On behalf of Solar Reactor Technologies (SRT), I would like to express our appreciation to the Senate Subcommittee on Energy Research and Development for inviting us to come here today and give testimony on this important legislation.

Prior to introducing my colleague, Dr. Peter Langhoff, who will describe Solar Reactor Technologies' innovative approach to solar hydrogen production, I felt that a brief description of our company's past and current activities would be appropriate.

Solar Reactor Technologies is a small business dedicated to research and development of propulsion systems, power generation and hydrogen production utilizing the thermal-photochemical synergy available in hydrogen, oxygen and halogens.

In February 1986, SRT was awarded an Air Force contract for just under a half million dollars to investigate a "Survivable 50 kw Solar Space Power System Using Radiation Augmented Fluid Technology" as a Strategic Defense Initiative Organization or SDIO asset. This program may lead to a solar power generation system that may provide a five-fold increase in power output without increasing the concentration ratio and collector size of known solar power generation systems. It is our belief that this technology will have significant impact on NASA and DOE solar energy programs.

Concurrently, with our SDIO program, SRT has dedicated a considerable amount of resources to researching alternative methods of producing hydrogen using solar energy. These methods, which we collectively call Radition Augmented Electrolysis, or RAYS, may present an economically viable method of producing hydrogen with solar energy.

To apply RAYS, SRT is now developing a pilot plant demonstration of the approach for future operation at the Kennedy Space Center. This demonstration would also support an SRT proposal to NASA-Kennedy Space Center, for the on-site production of liquid hydrogen propellant. This SRT effort, includes TRW, Space and Technology Group, the West German industrial group of UHDE GmbH and possible Israeli participation.

Over the last week I have travelled to West Germany and Israel to assemble the team members with appropriate commercially available hardware for the demonstration of RAYS. In Dortmund, I met with UHDE GmbH, who agreed to participate in the project. Later, I attended the SOLAR WORLD CONGRESS in Hamburg and met with Interatom, a subsidiary of Siemens AG, which is evaluating our technology as an alternate to nuclear power. I also learned that West German government and industries are developing a cooperative three year, one billion D-mark or $625 million, hydrogen research program.

In Israel I met with Luz International, which is completing a 90 megawatt solar thermal power plant. I also met with Ormat Turbines which has completed a 24 megawatt geothermal power plant. Both plants are in California and sell power to Southern California Edison. Luz and Ormat agreed to participate and contribute their technology in the proposed Kennedy project.

Also, in Israel I met with representatives from the Ministry of Energy and Ministry of Finance, who assured support including possible Israeli financial participation.

Hopefully, this brief introduction of SRT and my latest experience in West Germany and Israel, can provide you with a better perspective of SRT and foreign activities regarding solar hydrogen production.

In closing, my recommendation to the Senate is to enact the proposed legislation for hydrogen research programs or provide legislation that encourages private investment in approved programs with appropriate tax incentives. Ideally the government would see its way to implement both approaches to ensure American support of hydrogen research programs.

We hope that in your consideration of this legislation that you bear in mind the substantial contribution that small business entities, such as, our own company, have made to the advancement of U.S. technology.

I would like to now introduce Dr. Peter Langhoff, Vice President of Research, for a brief description of SRT's technological approach.

Thank you for your time and consideration.

Robin Z. Parker
Solar Reactor Technologies, Inc.

SOLAR REACTOR TECHNOLOGIES
2666 Tigertail Avenue • Suite 115 • Miami, FL 33133
(305) 854-2668 • FAX (305) 854-2739

A WRITTEN RECORD OF TESTIMONY ON

PHOTOELECTROCHEMICAL TECHNOLOGY FOR HYDROGEN PRODUCTION

CONCERNING BILLS S.1294, S.1295, S.1296

23rd September 1987

BEFORE THE SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT, UNITED STATES SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES, WASHINGTON, D.C.

Presented by:

Mr. Robin Z. Parker, President
Dr. Peter W. Langhoff, V.P., R & D
SOLAR REACTOR TECHNOLOGIES, INC.

PHOTOELECTROCHEMICAL TECHNOLOGY
FOR HYDROGEN PRODUCTION

Hydrogen, long recognized as a ubiquitous, clean-burning, efficient fuel is presently underutilized on a national scale as a significant thermal energy source. Continued research on and development of hydrogen fuel technology as a viable alternative to the combustion of our rapidly depleting fossil fuel reserves is of vital importance to the nation's economy and to our environmental well-being.

I. PRESENT HYDROGEN PRODUCTION METHODS AND PROBLEMS

Although small quantities of hydrogen can be produced with relative ease in a laboratory environment, large scale production methods are currently less cost-effective than is acceptable and rely heavily on fossil fuels for feedstream source materials and for the thermal energy needed to drive the relevant release processes. The primary large scale methods currently employed for releasing hydrogen include methane cracking, methanol dissociation, and electrolysis of aqueous solutions.

The problems to be addressed in these and other methods for hydrogen production for use as a fuel are, simply stated;

1) Identification of inexpensive, plentiful feedstream materials from which hydrogen can be released in appropriate form;

2) Refinement of efficient physical and chemical processes that will accomplish the release and storage of hydrogen;

3) Identification of inexpensive energy sources with which to drive the processes for the desired release of hydrogen.

Methane cracking requires fossil fuels both for the feedstream source of hydrogen and for the thermal energy to drive its release. Methanol dissociation, used to a lesser extent in large scale hydrogen production is subject to the same requirements. Thus, in the release of hydrogen for use as a fuel by methane cracking or methanol dissociation, the

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costs, when computed in a sensible fashion, significantly exceed the benefits for most applications. Exceptions are certain special uses, as in the liquid-phase combustion of hydrogen employed in our space program.

Electrochemical processes, while promising, are not yet cost effective on a large scale when sensible, comprehensive cost estimates are made. These processes involve dissociation of either acid or alkaline aqueous solutions (i.e., taking water and adding an acid or a base) and require an energy source, usually provided in the form of electricity. Although electrical energy may be obtained ultimately from any source, present reliance on fossil-fuel burning for large-scale power generation makes the production of hydrogen for use as a fuel by electrochemical means economically undesirable.

In summary, economical large-scale production of hydrogen for use as a fuel on a national level will require a dedicated research and development effort to overcome the cost factors that presently mitigate against such a program. Potential advantages offered by hydrogen combustion as a wide-spread energy source justify the investment required to implement this program. All sectors of the scientific and technical research communities can contribute to this endeavor. The following testimony on hydrogen production is made from the particular perspective of the high technology, privately-owned, small-business community, long regarded as an important source of innovation in technological problems.

II. <u>SOLAR REACTOR TECHNOLOGIES, INC. PHOTOELECTROCHEMICAL TECHNOLOGY RESEARCH AND DEVELOPMENT</u>

Solar Reactor Technologies, Inc., (SRT) is a high technology, privately-owned small business located in Miami, Florida. As have other small businesses, the Company has focused some of its attention on advanced energy systems for space and terrestrial applications, with particular reference to cost-effective, environmentally-sound hydrogen production techniques. As a consequence, SRT now holds 10 patents relating to hydrogen production technology. In the following testimony a brief descriptive account is provided of the hydrogen-production techniques devised by SRT in the course of a continuing research and development effort.

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Page Three

SRT'S RADIATION AUGUMENTED ELECTROLYSIS (RAYS)

One of the methods for large scale production of hydrogen under development by SRT which shows particular promise employs; 1) water as a feedstream material, 2) electrolysis and photochemistry in the essential hydrogen release process, and 3) sunlight as the energy source to drive the overall cycle.

The separation of hydrogen from water by the electrolysis of a current-carrying solution is a well-known laboratory exercise, although it is not yet commercially attractive on a large-scale. The SRT technique for commercial production of hydrogen employs an indirect approach to this separation, in which; (i) hydrogen chloride is dissolved in water, (ii) the resulting hydrochloric acid is separated into hydrogen and chlorine gas by electrolysis, and, (iii) the chlorine gas is converted to hydrogen chloride by reaction with steam, also releasing oxygen. Solar energy drives all steps in the reaction, resulting in the net production of hydrogen and oxygen from water. The advantages of this cycle relative to alternative methods are significant.

First, it must be recognized that decomposition of an aqueous solution by electrolysis requires a larger voltage than the so-called theoretical minimum. This higher voltage requirement, referred to as an "overvoltage", translates directly into wasted energy and higher cost. It has been observed in earlier studies, and confirmed by research at SRT, that significantly lower overvoltages are achieved using hydrochloric acid as an electrolyte, as opposed to other solutes, particularly sodium hydroxide and sulfuric acid, which are presently employed in large scale aqueous electrolysis.

Second, a considerable portion of the energy required to electrolyze a hydrochloric acid solution can be obtained directly from sunlight. It is known that the chloride ion has a strong tendency to form moderately complex structures in the presence of certain metal ions dissolved in aqueous solutions. It is characteristic of such species to efficiently absorb visible light. Complex ions also frequently show unusual electrochemical behavior. Earlier studies have demonstrated that certain complexes of iridium ion, for example with chloride can form gaseous hydrogen and chlorine directly when exposed to deep ultraviolet radiation.

In the SRT process this solar energy is employed to augument the electrolysis of hydrochloric acid solution. This process still requires application of electrical energy, but the energy requirement in the presence of sunlight is considerably lower than the dark.

Third, the chlorine gas produced along with hydrogen in the SRT electrolysis process is back-converted into hydrochloric acid to be used over again in a closed cycle. Industrial methods of back-converting to form hydrogen chloride react chlorine with hydrogen. This method would consume all of the hydrogen formed in the decomposition of hydrochloric acid. Instead, SRT has developed a method involving the direct reaction of chlorine gas with steam at moderately high temperatures, in the range of 600 °C to 800 °C (1100 °F to 1500 °F). Laboratory investigations by SRT indicate that the chlorine and steam react in a gas phase thermochemical process to form hydrogen chloride and oxygen. Consequently, the combined SRT process of photoelectrochemical and gas phase thermal reaction results in the net production of hydrogen and oxygen from water employing a cyclic process. This technology is termed Radiation Augmented Electrolysis (RAYS).

A special aspect of the SRT-RAYS photoelectrolysis process observed in the laboratory involves the photochemical changes produced when light falls on the iridium/ chloride complex, which appear to persist for one to two minutes after the light has been turned off. This suggests electrolysis of the hydrochloric acid solution containing the iridium chloride complex can be carried out in electrolysis cells of conventional industrial design, readily available at the present time. The photolysis would be carried out separately in external vessels, optimized for that purpose. The solutions would be rapidly pumped between the photolysis and electrolysis cells, so that residence time in each would be of the order of one to two minutes. This approach will greatly facilitate incorporation of the RAYS photoelectrochemical method into conventional large-scale electrolysis technology.

Another special aspect of SRT-RAYS technology compared with other photoelectrochemical methods is that light is absorbed by the solution and not by special electrodes. Previous studies have described solar assisted electrolysis processes in which specially prepared electrodes are the active elements. Unfortunately, the electrodes employed are generally expensive, delicate and short-lived, lasting only a few hours or a few days. By using photolysis of the solution rather than of the electrodes, SRT is able to achieve an economical process that is practical on a large industrial scale.

The SRT-RAYS process shows considerable promise of providing a cost-efficient, large-scale method for production of hydrogen as a national fuel. Continuing research and development is needed to bring this process, as well as others presently under study in the research and development community at large, forward to fruition on a national scale.

SRT's RADIATION AUGUMENTED FLUID TECHNOLOGY (RAFT)

The SRT-RAYS process requires only water, solar energy, and electrical energy for production of hydrogen and oxygen. It is highly desirable to explore the use of solar energy as a direct source of the electrical power required in the RAYS process. Accordingly, SRT is conducting research on and development of solar energy power systems which can serve as the prime energy source for a RAYS facility. These methods, generically designated as RAFT (Radiation Augmented Fluid Technology) utilize the light-absorbing characteristics of halogen fluids to drive physical and chemical energy production-processes. As illustrative examples of this technology, two promising versions of SRT-RAFT devices are described briefly in the following testimony.

One of the SRT-RAFT methods currently under development is based on a solar-powered closed-cycle gas turbine, driven with a light-absorbing halogen fluid. Such a system can operate at significantly higher working fluid temperatures than is possible with conventional black-body solar receivers, consequently, providing greater overall system efficiencies. Although this SRT-RAFT system is particularly advantageous in a space-power setting, for which it is presently designed, terrestrial applications are presently under study, including operation of the SRT-RAYS facility.

A second SRT-RAFT apparatus under development employs solar activation of halogen gas reacted with hydrogen. The energy released by this method is the sum of the chemical reaction energy of making hydrogen chloride, and the solar energy added to the halogen gas. In this case, a gas turbine is driven by hot hydrogen chloride gas, with subsequent back-conversion of the hydrogen chloride into hydrogen and chlorine, which can be continuously recycled through the apparatus. A proprietary solar-photochemical method is employed for carrying out back-conversion of hydrogen chloride.

The SRT-RAFT processes show considerable promise of providing efficient solar-energy power sources for driving the large-scale SRT-RAYS production of hydrogen fuel.

III. SUMMARY

The development of a national hydrogen fuel technology as a viable alternative to currently employed thermal energy sources must rate high on the list of priorities for allocation of funding resources. A number of factors auger well for the development of efficient, large-scale hydrogen production facilities consequent of sufficient funding levels; 1) Water, the very product of hydrogen combustion, provides a plentiful feedstream material from which hydrogen can be released; 2) A great array of chemical and physical processes involving hydrogen release have been studied to date under laboratory conditions with promising efficiencies; 3) Solar-energy devices under presently under development which can provide environmentally satisfactory energy for driving the large-scale release of hydrogen.

The SRT-RAYS and SRT-RAFT technologies described here for hydrogen production, and for providing the necessary driving energy from solar sources, are representative of a large class of developmental studies. These promising technologies can be brought on-line quickly with appropriate levels of funding. The scientific and technical development communities at large stand ready to move forward in implementing this program. We consequently support and applaud the allocation of resources for the development of an efficient and environmental satisfactory thermal energy source in the form of a national hydrogen fuel technology.

Senator FORD. Thank you very much.
Mr. Marshall.

STATEMENT OF RICHARD L. MARSHALL, CHIEF, COMBUSTION FUELS AND EMISSIONS, COMMERCIAL ENGINES, ENGINEERING DIVISION, PRATT & WHITNEY GROUP, UNITED TECHNOLOGIES CORP.

Mr. MARSHALL. Mr. Chairman, on behalf of United Technologies and Pratt & Whitney Group, I would like to take the opportunity to discuss aspects of S. 1296, a bill to establish the hydrogen research and development program.

At Pratt & Whitney we design, develop, manufacture, market and support commercial and military aircraft gas turbine engines on a worldwide basis. We also are the designers of the RL-10 liquid hydrogen-liquid oxygen rocket for the U.S. space program. Because of our experience with hydrogen as a propulsive fuel, I will briefly review some of the history using hydrogen and address some remarks to potential research and development work.

During the 1950s, Pratt & Whitney pioneered in the experimental use of hydrogen fuel in a conventional J-57 jet engine and in the preliminary development of an advanced hydrogen-fueled engine, the 304, for supersonic military reconnaissance aircraft. The work we did on component engine tests did demonstrate the ease of burning hydrogen fuel in a jet engine.

Following the earlier experiments with hydrogen in jet engines, Pratt & Whitney developed the first hydrogen-fueled rocket engines, the RL-10, which powers the upper stage of the Atlas/Centaur vehicle. This engine continues to enjoy a flawless record in this country's space program. To date there have been 282 firings in space, all without malfunction.

Currently Pratt & Whitney is working on propulsion technology required to power the proposed national aerospace plane, the NASP. This program is sponsored jointly by DOD and NASA. The NASP, designated the X-30, will utilize a conventional takeoff, a single stage propulsor and hydrogen fuel. It will be capable of hypersonic cruise, orbital insertion, conventional landing. The ultimate goal is achieving a Mach number of 25.

If we are to move toward a hydrogen-fueled aircraft or indeed toward a broad, hydrogen-energy based society, there are essentially three hurdles to overcome. First, we have to be able to produce hydrogen economically from renewable energy sources. Second, we must be able to distribute it. And third, we have to be able to store it.

We believe that hydrogen-fueled aircraft technology, while not developed, is significantly ahead of the technologies needed to produce, distribute and store hydrogen. The cost of producing hydrogen now makes it noncompetitive with other fuels for propulsion below hypersonic speeds.

With respect to title II of this bill, a very realistic question arises. Why would anyone want an aircraft powered by an engine burning liquid fuel?

First, liquid hydrogen provides more heating value per pound than any other fuel. This means that a given amount of hydrogen fuel should be able to propel an airplane faster and further than the same amount from any other fuel.

Second, liquid hydrogen provides far more cooling capacity than any other fuel, some 20 times that of regular jet fuel. Hydrogen cooling of the aircraft will be required to withstand the intense aerodynamic heating associated with very high speed flight.

Finally, we can improve existing jet engine cycles if they are designed to use the unique properties of hydrogen. Studies show that turbojet engines are attractive to about Mach 3, ramjets to about Mach 7, and Scramjets—that is, supersonic combustion ramjets—to Mach 20, and rockets above that.

The use of hydrogen is not without its engineering challenges. Liquid hydrogen must be stored at about minus 425 degrees Fahrenheit. It is an extreme cryogenic. Before it can be pumped, the pump and the lines to the pump must be cooled to this temperature. The tank, the inlet lines and the pump must be well insulated to prevent buildup of ice on the outside due to condensation of both air and water from the atmosphere.

Because of the cryogenic nature of the fuel, elastomers don't work as seals for joints, so new sealing techniques must be developed. Also thermal expansion and contraction in the fuel system is unusually large, so special designs are required to keep the joints tight and avoid over-stress.

Some metals become embrittled when subjected to hydrogen at certain pressures and temperatures. Some metals become embrittled due to low temperatures alone. Tests are necessary to characterize each of these materials used and to assure compatibility.

Like just about any fuel, liquid hydrogen is a safe fuel if properly handled. Hydrogen is very predictable. One has to design specifically with its unique properties and, anticipating failures, design in a failsafe manner. Safety rules must be followed.

Our test facilities all provide plentiful ventilation, especially around the top of the test stands, to allow rapid dissipation of leaking fuel and to prevent confinement of burning, expanding gases, thereby preventing detonations. At Pratt & Whitney we have been working successfully with hydrogen for years, first in the Suntan project, the 304, then with the RL-10 engine, and now with the NASP. The 282 firings of the RL-10 in space and the literally thousands of test firings on the ground are testament to this success.

The future of hydrogen aircraft of, indeed, a hydrogen-based economy is really based on the cost of delivered hydrogen.

We need to support work that leads to the economic production of hydrogen and to work out the problems of distribution and storage as called for in title I of this bill.

Research and development for aircraft and engines must fócus on achieving the long durability and safety now associated with commercial and military aircraft flying today.

Liquid hydrogen is an excellent fuel, but considerable work must be done before this highly efficient fuel will be in widespread use.

When hydrogen is economically available and there are systems for its safe distribution storage and use, you can be sure that Pratt & Whitney will be there to build dependable, high performance aircraft engines.

Thank you.

[The prepared statement of Mr. Marshall follows:]

S.1296, A BILL TO ESTABLISH A HYDROGEN RESEARCH
AND DEVELOPMENT PROGRAM

Statement of
United Technologies Corporation
Pratt & Whitney

September 23, 1987

By

Richard L. Marshall
Chief, Combustion Fuels & Emissions
Commercial Engines
Engineering Division, Pratt & Whitney

Prepared for

Senate Committee on Energy & Natural Resources

Subcommittee on Energy, Research and Development

Honorable Wendell Ford, Chairman

Mr. Chairman and members of the subcommittee:

On behalf of United Technologies Corporation and its Pratt & Whitney Group, I'd like to thank you for the opportunity to discuss aspects of S.1296, a Bill to establish a hydrogen research and development program.

At Pratt & Whitney, we design, develop, manufacture, market and support commercial and military aircraft gas turbine engines on a worldwide basis. We are also the designers and producers of the RL-10 liquid hydrogen - liquid oxygen rocket for the U.S. space program. Because of our experience with hydrogen as a propulsive fuel, I'll focus my remarks on S.1296 Title II - Hydrogen-Fueled Aircraft Research and Development.

During the 1950s, Pratt & Whitney pioneered in the experimental use of hydrogen fuel in a conventional jet engine and in the preliminary development of an advanced hydrogen-fueled engine for a supersonic military reconnaissance aircraft. We first began our work in 1955 under Air Force Sponsorship. The program was terminated by the Government before the engines were fully developed. The work we did, however, on component and engine tests did demonstrate the ease of burning hydrogen fuel in jet engines.

Following the early experiments with hydgrogen in jet engines, Pratt & Whitney developed the first hydrogen-fueled rocket engine, the RL-10, which powers the upper stage of the Atlas-Centaur vehicle. This engine continues to enjoy a flawless record in this country's space program. To date, there have been 282 firings in space, all without a malfunction.

Currently Pratt & Whitney is working on propulsion technologies required to power the proposed National Aerospace Plane, the NASP. This program is sponsored jointly by DOD and NASA. The NASP, designated X-30, will utilize a conventional takeoff, a single stage propulsor, and hydrogen fuel. It will be capable of hypersonic cruise, orbital insertion and conventional landing. The ultimate goal is achieving a Mach number of 25. Much will be learned from the NASP program which will be directly applicable to your Bill, S.1296, in particular Title II - Hydrogen-Fueled Aircraft Research and Development.

If we're to move toward a hydrogen-fueled aircraft or, indeed, toward a broad, hydrogen-energy based society, there essentially are three hurdles to overcome: First, we have to be able to produce hydrogen economically from renewable energy sources. Second, we have to be able to distribute it; and third, we have to be able to store it. These factors are relevant to S.1296 Title I - Hydrogen Production and Use. We believe that hydrogen-fueled aircraft technology, while not developed, is significantly ahead of the technologies needed to produce, distribute and store hydrogen. The cost of producing hydrogen now makes it non-competitive with other fuels for propulsion below hypersonic speed.

In the 1950s project, it was Pratt & Whitney's job to develop a hydrogen engine for what then was called the "Suntan" project, a high altitude, supersonic surveillance aircraft. We purchased a 500-pound per day capacity hydrogen liquefaction plant and installed it in a remote area of our plant in East Hartford, Connecticut.

We converted one of our J-57 turbojet engines to operate on liquid hydrogen fuel, and we began testing in 1956. Meanwhile, we designed a new engine, which we called the "304", which could take advantage of the unique properties of hydrogen.

I won't go into many engineering details of the 304 engine, but I should mention that we used liquid hydrogen at high pressure. The hydrogen drove a multistage turbine which powered a multistage fan which in turn compressed incoming air. Part of the hydrogen discharged from the turbine was injected and burned in the air-stream behind the fan. The remaining hydrogen was injected and burned in an afterburner, and the hot gases and air expanded through the nozzle to produce propulsive thrust.

For security reasons, we transferred hydrogen-fueled engine testing to our then new Development Center in West Palm Beach, Florida. The Air Force established a large hydrogen liquefaction plant nearby on a tract of land which we deeded to the government. The plant was able to produce 7000 pounds of hydrogen a day from liquid petroleum in a chemical process. The hydrogen was stored in a 100,000 gallon tank farm which was connected to our test cells.

Even before this plant was completed, the Air Force planned a much larger hydrogen liquefaction plant to meet the anticipated testing needs for developing the 304 engine. The second plant was built a few hundred yards away from the original installation and went into operation in 1959 with a capacity of 60,000 pounds per day. It was then the largest facility of its kind in the world. Natural gas was used as the feed stock to make hydrogen. This plant came too late for the "Suntan" program but turned out to be very useful in the space program that was to follow.

The first 304 engine tests began in September, 1957. We eventually built five 304 engines and ran them on liquid hydrogen fuel. From a technical standpoint, the program was very successful, and we learned a lot about the use of liquid hydrogen fuel. Although we had our share of development problems, none appeared to be insurmountable.

The engines were intended for the Lockheed CL-400, an airplane capable of Mach 2.5, which was being designed by Clarence "Kelly" Johnson at the Lockheed "skunk works." The "Suntan" Program continued until mid 1958 when it became apparent that, with the development of titanium aircraft structures to replace aluminum, and with advanced state-of-art engine cycles, the mission could be performed at lower cost with an aircraft that burned more conventional jet fuel.

So much for historical experience with hydrogen engines. Now let me address current day hydrogen engine activities.

As noted in National Aeronautical R&D Goals, February, 1987, Executive Office of the President, Office of Science and Technology Policy "... key technologies for advancing supersonic cruise capabilities have not been aggressively pursued by the U.S. since 1971 termination of the U.S.

Supersonic Transport program. However, the NASA-funded Supersonic Cruise Research program, which ended in 1981, established a constructive base for further advancement. Operational experience with the Concorde and SR-71 also provides a stepping stone for a second-generation supersonic transport." The Aeronautical Policy Review Committee believes that "the depth of foreign aeronautical resolve and the concerted national effort required to preserve American competitiveness are still largely underestimated. Sustained U.S. leadership will require greater achievement by all sectors--government, industry, and academia. Both the opportunity and challenge are unprecedented. Accordingly, the Committee believes that this challenge to our competitiveness is so important--not just to the nation's diverse aeronautics industry, but to the nation as a whole--that it now issues this call to action.... A decision to go forward with research on an aerospace plane was announced by President Reagan in his State of the Union address on February 4, 1986. The National Aero-Space Plane program, a bold new technology initiative to carry out the decision, is being conducted jointly by DOD and NASA. By the turn of the century, an air-breathing vehicle could take off from an airport runway and fly between 5 and 25 times the speed of sound to the edge of the earth's atmosphere and into low earth orbit. The plane would return to a conventional runway."

Pratt & Whitney has been and is eagerly and fully involved in all of these activities.

A very realistic question arises, "why would anyone want to have an aircraft powered by an engine burning liquid hydrogen?"

First, liquid hydrogen provides more heating value per pound than any other fuel. This means that a given amount of hydrogen fuel should be able to propel an airplane faster or farther than the same amount of any other fuel. Hydrogen, though, is the least dense of all fuels, and an aircraft would need relatively large fuel tanks. The theoretical performance advantage of hydrogen, therefore, can be obtained only if there are sufficiently light fuel tanks, and there is an airplane with low aerodynamic drag.

Second, liquid hydrogen provides far more cooling capacity than any other fuel--some 20 times that of regular jet fuel. This is an important factor for very high speed aircraft. Hydrogen cooling of the aircraft will be required to withstand the intense aerodynamic heating associated with very high speed flight in the upper atmosphere.

Finally, we can improve existing jet engine cycles if they are designed to use the unique properties of hydrogen. Studies show that specific impulse, a measure of propulsion effectiveness, favors air-breathing, hydrogen-fueled engines; air-breathing so that the oxidizer needn't be carried along, and hydrogen because of its high heating value and excellent cooling capacity. Turbojet engines are attractive to about Mach 3, ramjets to Mach 7, Scramjets (supersonic combustion ramjets) to Mach 20 and rockets above that.

The use of hydrogen is not without its engineering challenges. Liquid hydrogen must be stored at about -425°F; it is an extreme cryogenic. Before it can be pumped, the pump and the lines to the pump must be cooled to this temperature. Once the engine is started, the continuing flow keeps the lines and pump cool. The tank, inlet lines, and pump must be well insulated to prevent the buildup of ice on the outside due to condensation of air and water from the atmosphere.

Because of the cryogenic nature of the fuel, elastomers don't work as seals for joints, so new sealing techniques must be developed. Also, thermal expansion and contraction in the fuel system is unusually large, so special designs are required to keep joints tight and avoid overstress.

Some metals become embrittled when subjected to hydrogen at certain pressures and temperatures, and some metals become embrittled due to low temperature alone. Other metals have improved properties at low temperatures. Tests are necessary to characterize each of the materials used.

Like just about any fuel, liquid hydrogen is a safe fuel if properly handled. Hydrogen is very predictable. One has to design specifically for hydrogen with its unique properties, and, anticipating failures, design in a fail-safe manner. Safety rules must be followed.

Liquid hydrogen within a tank is completely inert unless mixed with air, and normally the gas above the liquid is gaseous hydrogen. As long as proper tank pressure is maintained, no air can get in. If heat leaks into liquid hydrogen tanks, hydrogen boils off, and the pressure must be relieved.

If liquid hydrogen is spilled on the ground, it boils as it cools the ground, and generates cold hydrogen vapor. When first evaporated, it has about the same density as air and stays near the ground. As soon as the gas is warmed a little, it becomes enormously buoyant. It rises quickly and dissipates rapidly. Thus, while spilled liquid at first produces a hazardous fuel-air mixture, it dissipates rapidly.

Gaseous hydrogen does not ignite spontaneously when mixed with air unless the mixture is heated to 1,000°F. It can, however, be ignited by a spark.

Our test facilities all provide plentiful ventilation, especially around the top of the test stands, to allow rapid dissipation of leaking fuel and to prevent confinement of burning, expanding gases, thereby preventing detonations. At Pratt & Whitney, we've been working successfully with hydrogen for years--first in the "Suntan" project, then with the RL-10 engine, and now with NASP. The 282 firings of the RL-10 in space and the literally thousands of test firings on the ground are testament to that success.

It's too early to tell just how important a fuel hydrogen will be in the future. But it holds great potential if it can be made economically from renewable energy sources, as called for in this bill.

The future of a hydrogen aircraft or, indeed, a hydrogen based economy is really based on two factors.

As long as petroleum or natural gas is generally available, hydrogen will be too expensive. Second, when hydrocarbons are not plentiful, then the cost of producing hydrogen and the infrastructure required to support it must be looked at in relation to other forms of energy, such as coal. We believe, though, that while we're not in an energy crisis, it's a good time to begin to work on some of the major questions that must be answered if hydrogen is to realize its promise. We must learn how to make it cheaper!

We need to support work that leads to the economic production of hydrogen, and to work out problems of distribution and storage--as called for in Title I of this bill. And we must consider the total energy consumed and the effect of hydrogen production on the environment.

Research and development for aircraft and engines must focus on achieving the long durability and safety now associated with commercial and military aircraft flying today. We believe hydrogen fuel will be required for hypersonic flight vehicles. Yet what is learned from application in hypersonic vehicles also will be useful for subsonic and supersonic aircraft designs, especially in the study of materials compatibility with cryogenic hydrogen.

Liquid hydrogen is an excellent fuel, yet we must assure safety in distribution and in use. They say engine designers love hydrogen. We do. But considerable work must be done before this highly efficient fuel will be in widespread use.

When hydrogen is economically available and there are systems for its safe distribution, storage, and use, you can be sure we'll be there to build dependable, high performance aircraft engines.

Thank you.

Senator FORD. Thank you very much, Mr. Marshall.

Both of you indicated some problem with storage. Mr. Langhoff, how do we store solar energy?

Dr. LANGHOFF. We store solar energy in the form of hydrogen, sir, in my view.

Senator FORD. There wouldn't be any direct generation. You could collect it, transmit it to Earth, but solar energy would have to be used as a renewable to get hydrogen.

You indicated 100 square miles of ocean water—500 square miles if you needed it—deriving from that what now?

Dr. LANGHOFF. That derives from the energy and the incident light flux in an average day on that area. We get about a kilowatt per square meter of power in solar energy coming down. So, it is a simple exercise if you know how much the national economy uses in a year's time.

Senator Ford. The general public—when you talk about energy, it comes through a line, and you flip a switch, and that's basically all. They see the space ship or rockets, and they understand the propulsion that is there.

How do we describe this and the use of this in general terms that the general public would understand?

Dr. LANGHOFF. The general public and, indeed, all of us need to know that if you take the national power usage and attribute it to individual—that is to say, to ask what is the power utilization per individual—it comes to 10 kilowatts approximately. If each individual had to pay out of his own pocket directly—he does pay for it. If he had to pay that for one day, that would be $25 a day approximately. We are each paying $25 a day not directly to our light bill, but in the goods—the energy content in the goods and services that we make use of. The public I think can understand that number. It is $12,000 a year per person. Each one of us has made the commitment—we have authorized someone by circumstance to expend that amount of dollars.

Another way to understand it is if you look at the nonrenewables that we are using up in meeting that energy need. If you need that much, 10 kilowatts per person, you have to burn at least 100 pounds of wood a day per person. You have personally authorized, through going along with the way our economy is set up, the burning of 100 pounds of wood. Or 70 pounds of coal would be the equivalent amount, or coming down into natural gas, 40 or so pounds of natural gas per person per day.

I think at that level the average person can understand what is involved in the way we live and the amount of thermal energy we need to heat this cavernous room or to drive the lights that are on us.

If we continue to use this—and I perhaps don't need to tell this to this committee. If we continue to use this energy at that rate, we will soon come to the end of it.

Solar energy continues to come down to us, and it is dissipated in driving our atmosphere, driving the air and making the winds that we are familiar with. If we take only a very tiny, small fraction of that energy, we can very easily meet our total energy needs. And if 25 percent is the conversion factor, as it is and as the Assistant Secretary has indicated to us in her testimony, it seems to me we need an all-out effort to take that very small fraction of the total solar input and turn it into satisfying our energy need rather than burning that methane, that natural gas, which we may need for something later on downstream. That is a gift that has been given to us by photosynthesis and by geological time, the long time in which it has been laid down. We may very much need those reserves for special application later on. We can take our energies from the solar energy that comes down.

And indeed, our company is very much engaged, as are other companies, in maximizing these conversion efficiencies.

Senator FORD. Mr. Marshall, you talked about the storage of liquid hydrogen and the problem that might—you said it was safe if it was handled right. Most of the problem is when things are handled wrong.

Do you have the storage of liquid hydrogen worked out with no problem? Say, aircraft whatever other use for it might be—has that storage been worked out? We heard earlier where there were tanks on the plane, then it was included inside I think, or normally where jet fuel A type I guess is being used today.

Mr. MARSHALL. I think there is a good understanding of those problems, but no, I don't think they have been worked out. Storage is a real technical concern.

The concern that I would have is—let's say, at airport sites one has to have liquid hydrogen available for the many planes that are coming in and out and anticipate more usage than perhaps is actually used. So, there is excess hydrogen available. At those temperatures of minus 425 degrees Fahrenheit, there is a tremendous heat loss. There would be tremendous heat loss even in those tanks in the airplane or very special requirements to insulate those tanks. So, my concern was from a technical viewpoint. There is a lot of energy consumed in getting hydrogen to that liquid state, and if you have to keep it for long periods of time, you are using a lot of energy to do so.

Senator FORD. We heard some testimony earlier today about the funds that were necessary, or at least some of the funds that were necessary, by the Federal Government. Do you all have any figure? Of course, the more money, the more you get to do. But there is a limit for efficiency and the cooperation of industrial cooperation. Do you all have any magic figure in your mind that we ought to be looking toward as we discuss these three pieces of legislation?

I don't want to put you on the spot, but we need your input because you know what it takes to keep the research and development moving forward at a good pace. We hope that the money we spend will be used efficiently, that we don't throw a lot of money at any one thing. I don't want to nickel and dime it to death either. So, is there some mean that we could go by?

Dr. LANGHOFF. If I may take the extreme case——

Senator FORD. Sure.

Dr. LANGHOFF [continuing]. Some years ago I worked for U.S. Army Missile Command at the time that the NASA program to reach the moon was in full scale. At that point the NASA budget was some $6 billion a year or so.

It seems to me the problem that we are facing here, in terms of constructing a national hydrogen fuel technology, certainly should carry the same weight as the program to reach the moon. And so, ultimately we are talking—in terms of scale now, we are talking about government expenditures in that range to bring these technologies——

Senator FORD. Are you talking about annually or over a period?

Dr. LANGHOFF. I am talking about an annual budget, sir, yes.

Senator FORD. You have gone to the ridiculous at $6 billion here. How about the sublime? Can you come down to the bottom of that?

Dr. LANGHOFF. Yes. I have thrown that on the table certainly as something to——

Senator FORD. I understood you gave the extreme.

Dr. LANGHOFF. Yes.

Senator FORD. Do you have any down side, what would be the least amount that otherwise we could just forget it because there wouldn't be sufficient funds in there for us——

Dr. LANGHOFF. No, no. I think what is very much needed is a program that carries forward the DOE sort of funding that has been carried on now. DOE is supporting science in my view. And so, a factor of 10 over the annual budget that is now allocated for energy related research by DOE certainly is an appropriate level to make a meaningful impact. To moving the science into the technology, a factor of 10 is a usual figure of merit.

Senator FORD. Yes.

Dr. LANGHOFF. And it would be very useful.

Senator FORD. Mr. Marshall, do you have any figure or anything that you——

Mr. MARSHALL. I don't have any numerical figure in mind. And relative to title I, I think it is very significant that monies of the order that are mentioned in title I be seed money to get something significantly started in the hydrogen production, storage and distribution research.

With respect to title II, I agree with the gentleman from NASA. I think a meaningful airplane demonstration, the $100 million would probably be woefully low for such a thing. Some meaningful ground demonstrations and partial flight operational characteristics certainly could be demonstrated.

Mr. PARKER. Mr. Chairman?

Senator FORD. Yes.

Mr. PARKER. If I may make just one comment regarding the budget items regarding hydrogen production. In light of not having sufficient funding from the government for hydrogen research, perhaps if the government would provide tax incentives for the private sector to do research, this could supplement government funding.

Senator FORD. I found in the last six years that we have seen a gradual and sometimes not so gradual decline in research and development in all arenas. I find that when oil prices come down, we stop buying oil for SPR, you know—all these things. And even though the funding is off budget and we will make a profit off of it at some point where we begin to sell it, it doesn't make a lot of sense to this Senator. And we keep trust funds on budget so you can spend for other things, such as foreign aid and social programs.

We all have our own way. And if you get 51 votes, you win; if you don't, you lose. So, I have adjusted to that reasonably well because I'm a very poor loser.

If we could have a combination of Federal funding and tax breaks as it relates to research, it would get industry and government working closer together. And technology transfer is a very sensitive issue. And we got into that in hearings the other day. So, technology transfer and how you do it—the best method to be sure that that is accommodated. There are too many things going on out there and too many smart people that are not being used. They are not given the opportunity to be the nut that walks down the street that has the biggest invention. You know what I am talking about. He is way out there and he is working on these things. And I am delighted to see him.

And somehow or another we need to enthuse and encourage those people, and particularly industry has some interest in keeping us ahead. Progress is our most important product. You have heard that advertised for a long time. And our progress hasn't been moving very fast.

I guess you all heard me say about the superconductor/supercollider basic breakthrough. It is ours. We are three to five years ahead of anyone else. And we will sit around while other countries go ahead and work at it. And we allowed it to get away from us.

Mr. PARKER. And one other point I might make. I just returned from West Germany. And the West German government and West German industries are working in a group effort. They are ready to allocate one billion Deutschmarks, or approximately $625 million for hydrogen research.

Senator FORD. We almost lost a war over the ability to put things together and derive gas from coal and that sort of thing.

You gentlemen are mighty interesting and whet the appetite some. So, what we will do is try to take your testimony now, and begin to look at it, and see how we can apply that to the three pieces of legislation.

There may be some questions. This has been one of those days where we have the debt ceiling up and a Gramm-Rudman-Hollings fix on the floor, and a few things like that. It has been difficult to get many of the members here. So, there may be questions in writing, and I hope that you will accept those and respond in a timely fashion—probably within the next two weeks. Outside of that, we will be then going to markup on these bills.

So, thank you all very much, and this hearing is adjourned.

[Whereupon, at 4:46 p.m., the hearing was adjourned.]

[Union Carbide Corp. submitted the following statement for the record:]

Statement of Union Carbide Corporation

submitted to the

Subcommittee on Energy, Research and Development

Committee on Energy and Natural Resources, U. S. Senate

September 23, 1987

The Federal Role in Hydrogen R&D

My name is Louis B. Batta, and I am the Business Manager, Contractual Research and Development for the Linde Division of Union Carbide Corporation.

The Linde Division of Union Carbide is an industrial gas company with significant involvement in the production and distribution of gaseous and liquid hydrogen. Linde is a large producer and it supplies hydrogen to a variety of customers in the electronics, metal, food, chemical, oil refining, and aerospace industries. However, in terms of the total industrial production of hydrogen, the largest producers are the ammonia and methanol producers and oil refiners who produce gaseous hydrogen for captive uses in their own processes. We continually monitor conditions that could affect the merchant market for hydrogen, including such factors as the availability and cost of feedstocks and electric power, the demand for hydrogen, and the research advances that may effect the supplies, distribution and markets for hydrogen.

Today, the primary source of hydrogen is natural gas. The amount used for hydrogen production is a very small fraction of the total natural gas consumed by the residential, commercial, and industrial sectors. Natural gas currently is abundant and available at reasonable prices; however, the potential for a sustained energy supply interruption in the short term, and the expected depletion of conventional fossil energy resources over the long term, may ultimately require the development of new commercial sources for hydrogen. These sources could include coal, tar sand, and the electrolytic dissociation of water using electric power generated by hydro, solar, and in the even longer range, nuclear fusion.

Hydrogen has several properties--long distance transportability, ease of storage, and enviromental acceptability--that make it attractive for use as a fuel. It cannot, however, be viewed as an energy resource because it requires more energy to produce hydrogen than it provides as a useful energy source. This is particularly true of liquid hydrogen since the liquefaction process is also highly energy intensive. We do not believe that hydrogen will ever come to be regarded as a reasonable or satisfactory solution to the decline in conventional energy resources. In fact, the potential for the development of materials which are super-conducting at relatively high temperatures could provide the technology for the transmission of electricty at much higher efficiencies. This would certainly reduce the attractivness of using electric power to produce hydrogen for basic energy purposes.

We believe that liquid hydrogen will continue to have an important role as a transportation fuel in applications where there is no possibility for substitution. These applications include space transport such as the shuttle and the proposed heavy-lift vehicle, and high-performance hypersonic aircraft such as the national aerospace plane. In contrast, a recent NASA-sponsored study dealing with the next generation of high-speed civil air transport vehicles concluded that the very property of liquid hydrogen-- its low density-- that makes it the premier fuel for space transport, makes it unattractive for civil air transport. Hydrogen fuel would take up too much passenger space and, hence, its use would not be economical.

Union Carbide, and others in the industrial gases industry, have the technologies and the facilities necessary to serve the existing hydrogen markets, including the resources for production, liquefaction, transport, storage, and safe use. We can predict market growth reliably and, because of this confidence, are willing and able to make the necessary investments in applied research, technology, production plants, and equipment required for the commercial market as it is projected to grow. In our view, Federal incentives in this area are neither needed nor warranted.

Government incentives, however, may be required to stimulate the development of new, non-commercial hydrogen applications that represent a high risk for private investment because of technical or market uncertanties. Government support may also be required to reduce the risks associated with building the production capabilities necessary to supply a rapid growth in demand for liquid hydrogen for space applications.

In summary, Union Carbide's views regarding the need for developing technology pertaining to new uses for hydrogen and new production processes are:

- The industrial gas industry can continue to provide the technology and financial resources necessary to serve the merchant hydrogen market so long as conventional feedstocks such as natural gas or natural gas condensates are available.

- Development of new technologies for producing hydrogen from non-conventional sources such as renewable resources may ultimately require Government incentives and/or sponsorship.

- The demand for liquid hydrogen for space transport and hypersonic vehicle use is not completely defined. It is potentially huge, but somewhat uncertain. This poses a high risk for the private investment necessary to develop the specialized technologies and facilities that may be required to satisfy this unique market. Some form of government support may be necessary to mitigate the technical and financial risks.

- In the immediate future, Federal research and development on hydrogen should be tailored to and carefully focused on the specific mission or project, and undertaken as part of the overall project development.

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APPENDIX

Responses to Additional Questions

Questions to DOE

9/23/87 Hearing on Fuel Cells and Hydrogen Research

1) How much money was appropriated to fuel cells and to hydrogen research in FY87? How much has been spent? Has DOE proposed any deferrals or recissions of moneys in either of these areas? If there are deferrals, does DOE intend to spend the left-over money in these areas during the next fiscal year? What are the budget requests in these areas for FY88? How much money has been spent to date on fuel cells and hydrogen research?

2) How does DOE coordinate and integrate the various elements of its research efforts in hydrogen and fuel cells, especially in view of the fact that much of the research is spread among several departmental divisions?

3) How does DOE coordinate its research in fuel cells and hydrogen with NASA, DOT, Commerce Department and other Federal agencies?

4) The Department's effectiveness in pursuing basic, long-term, high-risk research and development depends largely on technology transfer. Could you provide specific examples of where this has taken place? How successful would you rate your technology transfer programs? How do you coordinate with the private sector on other matters, such as program planning and priorities?

5) Do you think that, 5 or 10 years from now, we will be buying fuel cells from Germany or Japan, or do you think we'll have our own commercial product by then? I ask this question because I am concerned about a statement made by the Office

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of Technology Assessment in their report on new Electric Power Technologies (July 1985) that European and Japanese vendors, assisted by their respective governments, have been more successful than U.S. vendors in developing new energy technologies. Why do you think this is the case?

6) Do we participate in any joint ventures with foreign countries on fuel cell or hydrogen research? Who owns the patents in these instances? Is it possible that we may be exporting our patents to the detriment of our own commercial interests? What should be done about technology transfer to our foreign competitors?

Department of Energy
Washington, DC 20585
January 26, 1988

Honorable James A. McClure
United States Senate
Washington, D.C. 20510

Dear Senator McClure:

On September 23, 1987, Donna R. Fitzpatrick, Assistant Secretary for Conservation and Renewable Energy, appeared before the Energy and Natural Resources Subcommittee on Energy Research and Development to discuss S. 1294, S. 1295, and S. 1296, bills relating to the Department's hydrogen research and fuel cell programs. Ms. Fitzpatrick was accompanied by Robert L. San Martin, Deputy Assistant Secretary for Renewable Energy.

Following the hearing, you submitted written questions through Chairman Ford for our response. Enclosed are the answers to those questions, which also have been sent to the Committee staff.

If you have any questions, please have your staff call Michael Gilmore on 586-4277. He will be happy to assist.

Sincerely,

T. Thomas Todd
for Robert G. Rabben
Assistant General Counsel
for Legislation

Enclosures

Celebrating the U.S. Constitution Bicentennial — 1787-1987

Department of Energy
Washington, DC 20585

January 26, 1938

Honorable Wendell H. Ford
Chairman
Subcommittee on Energy Research and
  Development
Committee on Energy and Natural Resources
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

On September 23, 1987, Donna R. Fitzpatrick, Assistant Secretary for Conservation and Renewable Energy, appeared before your subcommittee to discuss S. 1294, S. 1295, and S. 1296, bills relating to the Department's hydrogen research and fuel cell programs. Ms. Fitzpatrick was accompanied by Robert L. San Martin, Deputy Assistant Secretary for Renewable Energy.

Following that hearing, Senator James A. McClure submitted through you written questions for our response to supplement the record. Enclosed are the answers to those questions which have also been sent to Senator McClure and to the Committee staff

If you have any questions, please have your staff call Michael Gilmore on 586-4277. He will be happy to assist.

Sincerely,

Robert G. Rabben
Assistant General Counsel
for Legislation

Enclosures

QUESTION 1: How much money was appropriated to fuel cells and to hydrogen research in FY87? How much has been spent? Has DOE proposed any deferrals or rescissions of moneys in either of these areas? If there are deferrals, does DOE intend to spend the left-over money in these areas during the next fiscal year? What are the budget requests in these areas for FY88? How much money has been spent to date on fuel cells and hydrogen research?

ANSWER: DOE has been appropriated a total of $30.0M for fuel cell research and $30.2M for hydrogen research in FY 1987. The fuel cell program consists of $28.1M for fuel cell development for electric power generation as part of DOE's Fossil Energy Program; $1.0M to conduct research and development on fuel cells for transportation systems including phosphoric acid and Solid Polymer Electrolyte (also known as Proton Exchange Membrane) fuel cells; and $0.8M for fundamental research on fuel cells. The hydrogen program consists of $27.2M for non-mission-related research and $3.0M for mission-related research. All of these funds have been spent with the exception of $8.9M in the Fossil Energy fuel cell program for which agreements involving their expenditure are currently under negotiation. There are no plans for deferral or rescission of these funds.

The FY 1988 budget request included $5.2M for the Fossil Energy fuel cell program and $0.4M for the fuel cells for transportation effort. The hydrogen research budget request for FY 1988 is approximately the same as the FY 1987 appropriation.

The Department of Energy has spent $246.4M on fossil-energy-related fuel cell research and $9.6M for transportation fuel cell research since 1980. DOE has spent approximately $313M on hydrogen-technology-related research since 1976.

QUESTION 2: How does DOE coordinate and integrate the various elements of its research efforts in hydrogen and fuel cells, especially in view of the fact that much of the research is spread among several departmental divisions?

ANSWER: The hydrogen activities within DOE continue to be coordinated through the Hydrogen Energy Coordinating Committee (HECC). This committee functions to improve communications between various groups performing research related to hydrogen. The HECC holds meetings at which recent progress is reviewed, and a formal talk on a current topic of interest to hydrogen researchers is presented. Minutes are prepared and distributed to attendees and other interested persons. In addition, HECC publishes an annual summary of hydrogen projects. A copy of the most recent summary is attached.*

The fuel cell programs are coordinated by various means. Internal DOE coordination is accomplished by quarterly meetings between the Fossil Energy, Transportation, and Energy Storage staffs at which program plans, proposals, and project status are reviewed and discussed.

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*Committee Note.--The summary has been retained in Subcommittee files.

A National Fuel Cell Coordinating Group exists to share information and coordinate programs among government institutions and the private sector interests. Participants in this effort include DOE project managers, in addition to National Laboratory staffs, the Electric Power Research Institute, the Gas Research Institute, and private sector fuel cell developers. The DOE Energy Materials Coordinating Committee is another forum for coordination through its subcommittee on electrochemical technology which reviews and coordinates materials-related research within DOE, including research related to fuel cells.

Finally, special activities are conducted as needed by DOE or through professional societies such as the Electrochemical Society. An example of such an activity is the task force meeting on the role of "Interfaces in fuel cell and metal-air battery electrochemical reactions" in September 1987. The purpose of this meeting was to consider problem areas in electrochemical science which would benefit from new theoretical treatments and experimental techniques and initiate dialogue between individuals performing the fundamental research and those concerned with electrochemical processes in energy technologies.

QUESTION 3: How does DOE coordinate its research in fuel cells and hydrogen with NASA, DOT, Commerce Department and other Federal agencies?

ANSWER: Fuel cell research at other Federal agencies is primarily coordinated through the National Fuel Cell Coordinating Group (NFCCG) and the Interagency Advanced Power Group (IAPG). The NFCCG, which includes DOE, DOD, NASA, EPRI, and AGA, coordinates programs and research projects among the various public and private entities conducting fuel cell research. The IAPG coordinates all projects in power-related research and conducts meetings, publishes project summaries, and establishes data bases so that each agency can be apprised of the research being conducted by others. Additional coordination is achieved via an International Fuel Cell meeting held annually; professional society interactions through the Electrochemical Society, such as special symposia; and direct interaction with industry and universities.

DOE has held discussions with or visited project offices at NASA, DARPA, the Air Force, and the Army for the purpose of improving coordination of hydrogen research programs. A five-year plan for hydrogen activities is currently being developed with NASA and other agencies, including DOD.

QUESTION 4: The Department's effectiveness in pursuing basic, long-term, high-risk research and development depends largely on technology transfer. Could you provide specific examples of where this has taken place? How successful would you rate your technology transfer programs? How do you coordinate with the private sector on other matters, such as program planning and priorities?

ANSWER: The technology transfer programs for both fuel cells and hydrogen activities are carefully planned and integrated with input from the private sector and have been successful. Examples of successful technology transfer in these areas are discussed below.

Currently, phosphoric acid fuel cells are being offered by the International Fuel Cells Corporation in two sizes, 11MW for electric utility power generation and 200kW for on-site commercial and industrial applications. Additionally, Westinghouse is developing technology for a 1.5MW demonstration power plant. The technology base for these applications was established through cooperative research within the Department. Molten carbonate, solid oxide, and proton exchange membrane systems are farther from commercialization, but private sector developers are planning market entry in the future.

Our research on membranes and catalysts for proton exchange membrane fuel cells has attracted considerable industrial interest. This interest has resulted in several agreements which are either in place or are in the final stages of negotiation. Both Dupont and Dow Chemical have supplied membranes and are working closely with DOE researchers in investigating proton exchange membrane technology fuel cells for transportation. Additionally, General Motors has been interested in the DOE fuel cell program since its inception and has contracted with the Los Alamos National Laboratory to conduct research into methanol fuel processing technologies.

Several spin-off technologies resulting from DOE hydrogen research have resulted in commercial products including metal hydride thermally driven compressors, static feed water electrolyzers for regenerative electric energy storage, solid polymer electrolyte electrolysis technology for generator cooling, and extraterrestrial liquefaction of hydrogen via metal hydrides for component cooling.

QUESTION 5: Do you think that, 5 or 10 years from now, we will be buying fuel cells from Germany or Japan, or do you think we'll have our own commercial product by then? I ask this question because I am concerned about a statement made by the Office of Technology Assessment in their report on new Electric Power Technologies (July 1985) that European and Japanese vendors, assisted by their respective governments, have been more successful than U.S. vendors in developing new energy technologies. Why do you think this is the case?

ANSWER: The United States currently leads the world in fuel cell technology, with some products in the early stages of market entry. While it is difficult to predict the future, we believe that several other U.S. fuel cell products could well be on the market in five to ten years, in addition to products manufactured in Europe and Japan.

Multi-national efforts by industry make it difficult to differentiate the progress of individual country activities. However, we expect the U.S. to remain very competitive in this international market.

QUESTION 6: Do we participate in any joint ventures with foreign countries on fuel cell or hydrogen research? Who owns the patents in these instances? Is it possible that we may be exporting our patents to the detriment of our own commercial interests? What should be done about technology transfer to our foreign competitors?

ANSWER: The Department of Energy does not participate in any joint ventures with specific individual foreign countries on fuel cell or hydrogen research. However, we do participate in International Energy Agency (IEA) agreements on some activities. For example, in hydrogen research, DOE participates in task share agreements through the IEA. In these commitments, DOE agrees to share research information with the participating countries in exchange for in-kind information on other hydrogen research projects. In all cases, the U.S. has protected patent rights to all technology developed in this country, and participation through such agreements is viewed as a way to leverage R&D funds during these difficult fiscal times.

The Office of Fossil Energy also has some international cooperative agreements in these areas, but they mainly involve the exchange of information at this time. The U.S. retains all of its rights in these activities as well. U.S. companies, on their own, have been pursuing the development of ties with foreign companies. Wherever possible, patent rights to technology developed in this country should be protected.

POST-HEARING QUESTIONS

Hearing on S. 1294, S. 1295 and S. 1296

September 23, 1987

Questions from Senator Spark Matsunaga

For Mr. Frank Spillers, President, Industrial Fuel Cell Association

1. In your testimony, you suggested that the time may be approaching to formulate performance and manufacturing standards for fuel cells.

(a) Please clarify whether this recommendation is confined to phosphoric acid fuel cells, as distinguished fron molten carbonate or solid electrolyte types still under development?

(b) Do you suggest that the Industrial Fuel Cell Association serve in an advisory capacity to the Bureau of Standards as these performance and manufacturing standards are being formulated?

Questions to Outside Witnesses

9/23/87 Hearing on Fuel Cells and Hydrogen Research

1) Do you feel that the Department of Energy is effective in coordinating its research (in fuel cells and hydrogen) to be responsive to commercial interests?

2) Do you feel that DOE's programs advance the research and development to a sufficient degree of maturity to enable the private sector to make use of DOE's work? Or would you rather see DOE take the work into a more advanced stage?

3) Do you feel that DOE is doing a good job in transferring these technologies to the private sector? What improvements would you suggest in the area of technology transfer?

4) Is there any sentiment out in the private sector that, because DOE focuses primarily on long-term, high-risk research and development, that most of DOE's work is useless? Or do you feel that their work is meaningful and beneficial to the overall advancement of fuel cell and hydrogen technologies?

IFCA

INDUSTRIAL FUEL CELL ASSOCIATION

Suite 200
1627 K Street, NW
Washington, D.C. 20006

November 16, 1987

1987 NOV 17 AM 8 04

The Honorable Wendell H. Ford
Chairman
Subcommittee on Energy Research
and Development
Committee on Energy and Natural Resources
United States Senate
Washington, D.C. 20510-6150

Dear Senator Ford:

Enclosed you will find my answers to the follow-up questions posed by the members of your Subcommittee, Senators Matsunaga and McClure, regarding my recent testimony on September 23, 1987 on S. 1294, S. 1295, and S. 1296. These proposed bills related to fuel cell and hydrogen research and development.

I wish to express my thanks to you and the other members of the Subcommittee for having allowed me the opportunity to present my testimony last September and to respond to the follow-up questions. I would be pleased to reply to any additional questions regarding my testimony, the status of fuel cell technology, or the needs of the fuel cell community that your Subcommittee may wish to have answered.

Sincerely,

Frank W. Spillers
President

MR. FRANK SPILLERS' ANSWERS TO QUESTIONS FROM THE SENATE SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

QUESTION NUMBER 1: In your testimony, you suggested that the time may be approaching to formulate performance and manufacturing standards for fuel cells. (a) Please clarify whether this recommendation is confined to phosphoric acid fuel cells, as distinguished from molten carbonate or solid electrolyte types still under development? (b) Do you suggest that the Industrial Fuel Cell Association serve in an advisory capacity to the Bureau of Standards as these performance and manufacturing standards are being formulated?

ANSWER TO PART (a): Currently, one fuel cell technology, the Phosphoric Acid (PAFC) system, is approaching commercial use in the electric and gas utility industries and, possibly, in other markets and applications. Unfortunately, at this time, there are few if any PAFC standards that are generally accepted by both users and suppliers in all of the applications (i.e., utilities, transportation, etc.) likely to be served by this system; such standards are, in fact, urgently needed. Moreover, within the next two to five years, standards for Molten Carbonate (MCFC) and Membrane Fuel Cell systems will also very likely be necessary. Therefore, I urge Congress to help initiate the process of developing fuel cell standards as soon as possible. This work should be initiated soon, if we as a nation want to encourage the domestic use and manufacture of fuel cells.

As a first step, I urge that a joint Federal-industry study be started that deals with the applicability to PAFC (and other fuel cell technologies in the future) of existing standards, (such as for piping, electrical, construction, environmental, etc.). Such a study would quickly identify acceptable standards that would not have to be created from scratch.

ANSWER TO PART b: In my testimony to the Subcommittee on September 23, 1987, I strongly recommended that a start be made on fuel cell performance and manufacturing standards. Although not explicitly stated in my testimony, I do recommend that, during the initial phases, the leadership of this activity reside with the Federal government, in particular, with the National Bureau of Standards, working in concert with the private sector.

The Industrial Fuel Cell Association (IFCA) would welcome the opportunity to work with the Bureau of Standards in an advisory capacity to initiate the process of identifying and formulating standards for the fuel cell community. Since the membership of our Association includes potential users from a variety of industries as well as suppliers of fuel cells, it can make immediate and significant contributions to the preparation of needed standards.

In addition to IFCA, we would recommend inviting other non-governmental institutions and groups, such as the American Society of Mechanical Engineers, that have a strong interest in fuel cell technologies and standards, to contribute their expertise and talents. We also recommend that other elements of the Executive Branch, (specifically, the Fossil and Conservation elements of the Department of Energy, U.S. AID, etc.), be invited to play a role in this activity.

QUESTION NUMBER 1: Do you feel that the Department of Energy is effective in coordinating its research (in fuel cell and hydrogen) to be responsive to commercial interests?

ANSWER TO QUESTION NUMBER 1: In the past, the Industrial Fuel Cell Association has taken the position that coordination among the programs within the Department of Energy (DOE) having responsibility for fuel cell R&D has been inadequate. We see no reason to change our view of this issue. The Association sees even less coordination taking place between the fuel cell and hydrogen R&D groups.

Frankly, we are concerned that the DOE Fossil program, sponsor of the largest fuel cell R&D program within the Department, may be overstepping its role. For example, the Fossil program is undertaking transportation-related fuel cell R&D which, in our opinion, is best conducted under the aegis of DOE-Conservation's Transportation program. Likewise, industrial applications of fuel cells are better served by the Office of Industrial Programs under Conservation. IFCA is concerned that the appropriateness of this research and its value and timeliness to the private sector will be in jeopardy because of Fossil's failure to adequately coordinate its work.

QUESTION NUMBER 2: Do you feel that DOE's programs advance the research and development to a sufficient degree of maturity to enable the private sector to make use of DOE's work? Or would you rather see DOE take the work into a more advanced stage?

ANSWER TO QUESTION 2: IFCA believes that the DOE program in fuel cells is too narrowly focused on meeting the needs of the electric and gas utility industries. DOE should be supporting fuel cell research for other applications and markets, particularly, for transportation and industrial uses, in addition to the utility-oriented R&D.

In the recent past, IFCA offered to cost-share with DOE/Fossil studies of industrial applications for fuel cells. The Association was turned down! Subsequently, we offered to cost-share a program to test fuel cell systems at industrial sites, such as in chlor-alkali plants and steel mills. Again, we were turned down by DOE Fossil.

There are strong technical reasons to believe that, with a minimum level of support from DOE, fuel cells could become commercial realities in applications such as the two just mentioned, and do so quicker than in the electric and gas utility markets. This can only happen, however, if industrial users obtain hands-on operational experience with fuel cells in their own factory environment, an opportunity IFCA was attempting to provide, and one that DOE has rejected. Congress can play a crucial role in the future of this technology by changing DOE's attitude; without such intervention, the use and production of fuel cell systems in this country may be seriously delayed. Specifically, we advocate the following:

-DOE's Conservation programs, with the assistance of the Fossil Energy program and industry, should be asked to analyze the potential for fuel cells in the industrial and transportation applications. If warranted, these program offices should then define and initiate fuel cell R&D to encompass these applications.

-As a crucial step in the process of enabling private sector suppliers to bring fuel cell technology to the market place, DOE-Conservation's Office of Industrial Programs should be asked to define a program of cost-shared, on-site testing of fuel cells in industrial settings.

QUESTION NUMBER 3: Do you feel that DOE is doing a good job in transferring these technologies to the private sector? What improvements would you suggest in the areas of technology transfer?

ANSWER TO QUESTION NUMBER 3: The Association believes that the DOE Fossil program office is performing an inadequate job in transferring fuel cell technology to the private sector. This is because its primary focus is on long-term research, rather than on a balanced R&D program. In our opinion, a balanced fuel cell R&D program would comprise:

-Development and testing of fuel cells in user environments

-R&D aimed at a broader range of applications and markets, as well as the electric and gas utilities

-Greatly strengthened efforts in applied fuel cell and electrochemical research, especially that being conducted under Renewable Energy's Energy Storage program

-Initiation of an effective technical information dissemination (TID) activity. (DOE conducts essentially no fuel cell TID program today!)

-Increased involvement in DOE's fuel cell R&D efforts of small, high-technology businesses interested in commercializing the technology as rapidly as possible.

QUESTION NUMBER 4: Is there any sentiment out in the private sector that, because DOE focuses primarily on long-term, high-risk research and development, that most of DOE's work is useless? Or do you feel that their work is meaningful and beneficial to the overall advancement of fuel cell and hydrogen technologies?

ANSWER TO QUESTION NUMBER 4: We believe that the DOE fuel cell program is not useless--far from it. However, we are concerned that it is not as cost-effective as it can and should be. Let me explain as follows:

The Association and its members would like to see an end to the Federal role in fuel cell R&D as soon as possible. By arbitrarily continuing its emphasis on long-term R&D for applications that are likely to develop and mature some time well into the next century, if at all, DOE-Fossil's fuel cell program promises to be around for a long time. By contrast, a balanced R&D effort, of the type conducted by many other research programs within the Department of Energy and recommended by IFCA, would support the private sector's efforts to commercialize the technology in this country as soon as possible. Consequently, federal R&D support would be provided over a much shorter period of time. Moreover, because commercialization of fuel cells would take place at an earlier time than under the current R&D program, the balanced R&D program will also result in bringing funds back into the Treasury in the form of tax revenues.

Overall, the balanced approach is likely to be less of a burden to the American taxpayer and will enable the federal government to phase out its fuel cell R&D involvement at an earlier date.

Questions to Outside Witnesses

9/23/87 Hearing on Fuel Cells and Hydrogen Research

1) Do you feel that the Department of Energy is effective in coordinating its research (in fuel cells and hydrogen) to be responsive to commercial interests?

2) Do you feel that DOE's programs advance the research and development to a sufficient degree of maturity to enable the private sector to make use of DOE's work? Or would you rather see DOE take the work into a more advanced stage?

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THE FUEL CELL USERS GROUP
OF THE ELECTRIC UTILITY INDUSTRY, Inc.

1101 Connecticut Avenue, NW
Suite 700
Washington, DC 20036
202/457-0868

'87 NOV 24 AM 8 35

November 20, 1987

Senator Wendell H. Ford
Chairman, Subcommittee on
Energy Research and Development
Senate Committee on Energy and
Natural Resources
Washington, DC 20510-6150

Dear Senator Ford:

On behalf of the Fuel Cell Users Group of the Electric Utility Industry, Inc., I am responding to your letter and questions of November 2, 1987.

We appreciate the Subcommittee's interest in fuel cell research and development and urge your continued support.

Sincerely,

for Jeffrey A. Serfass

Eugene Sturgeon
Director, External Relations

ES:lda
enc.

Questions to Outside Witnesses

9/23/87 Hearing on Fuel Cells and Hydrogen Research

1) Do you feel that the Department of Energy is effective in coordinating its research (in fuel cells and hydrogen) to be responsive to commercial interests?

The Fuel Cell Users Group of the Electric Utility Industry, Inc. is very familiar with the Department of Energy's fuel cell program, but is less familiar with hydrogen activities and any attempt to coordinate them. From our point of view, the combined interests of fuel cells and hydrogen can only be successfully addressed if the phosphoric acid fuel cell powerplant becomes a commercial option, preferably sooner rather than later. Our answers to the next two questions address the remaining obstacles to fuel cell commercialization.

2) Do you feel that DOE's programs advance the research and development to a sufficient degree of maturity to enable the private sector to make use of DOE's work? Or would you rather see DOE take the work into a more advanced stage?

DOE's funding of fuel cell research, in combination with privately funded research, is responsible for bringing fuel cell development to the point where commercial application can be considered. However, fuel cell powerplants will not be commercially utilized by the private sector until (1) their costs are competitive with alternative ways of generating electricity and (2) until there is an acceptable reliability record, beginning with a multiple-year demonstration. DOE's research program addresses the first of these requirements.

DOE has tried in its recent proposed budgets to convince Congress that DOE's technology development is complete and the ability to build a fuel cell powerplant has been proven. Unfortunately, as many utilities have indicated by their reactions over the last two years to attempts to market current technology, the technology is not yet cost competitive, and it won't be until identified component advances can be completed through a significant development effort.

Unfortunately, funds Congress has appropriated for technology development have a tortuous path before they reach the developer who will advance the technology. Contracting for technology development efforts, notably the International Fuel Cells configuration B advanced phosphoric acid stack, has taken much longer than we would have liked or than may have been necessary. As a result, this stack technology will not be available for early demonstrations needed by the electric utility industry beginning in 1989. The Department of Energy has not been responsive to these commercial interests.

3) Do you feel that DOE is doing a good job in transferring these technologies to the private sector? What improvements would you suggest in the area of technology transfer?

DOE usually falls short of completing technology transfer activities because its support stops at the proof-of-concept stage. The highest cost and risk in the development process occurs beyond this stage, beginning with major demonstration projects needed to prove system capability and attain operating experience on commercial-like equipment. In some cases, the cost and the risk of the demonstration projects are too much for industry to accept on its own.

DOE's technology development programs are often built upon a relationship of mutual support and interest between the federal government and private industry. If this relationship is abandoned by the federal government before the technology is proven, future efforts to establish such joint efforts are jeopardized. Under these circumstances, both the private sector and the public fail to realize the potential benefits of the entire development effort.

We suggest a DOE policy and budget that includes such technology transfer support when the private sector cannot justify bearing the entire costs alone.

4) Is there any sentiment out in the private sector that, because DOE focuses primarily on long-term, high-risk research and development, that most of DOE's work is useless? Or do you feel that their work is meaningful and beneficial to the overall advancement of fuel cell and hydrogen technologies?

We certainly do not feel that DOE's long term focus is useless. High risk long term research is of great interest to public and private utilities alike. Hydrogen research is a good example of this. We would merely add that where success in nearer term research, such as phosphoric acid fuel cell efforts, will have a tremendous impact on the application of longer term technology development efforts, such as hydrogen utilization, that a coordinated strategy be developed to help all efforts be productively channelled. We are unaware of any such coordination in this arena.

[redacted] Center for
Electrochemical Systems and Hydrogen Research

[redacted]

238 Wisenbaker Engineering Research Center
Texas Engineering Experiment Station
The Texas A&M University System
College Station, Texas 77843-3577
(409) 845-8281

November 23, 1987

Senator Wendell H. Ford
Chairman, Subcommittee on Energy
Research and Development
United States Senate
Room 173A, Russell Building
Washington, D.C. 20510-6150

Dear Senator:

Please find enclosed responses to the questions of Senator McClure sent with your letter of November 2, 1987.

It was a privilege to be able to participate in the hearings.

Sincerely,

John Appleby

A. John Appleby
Professor and Director
Center for Electrochemical Systems
and Hydrogen Research

AJA:ja

Enclosure

TELEFAX 4098459287 • TELEX 5108927689 TXCM COSN

Replies to Senator McClure's Questions to Outside Witnesses,
9/23/87 hearing on Fuel Cells and Hydrogen Research
(S. 1294, 1295 and 1296)

1. There is ***no*** coordination in research at DOE between fuel cells and hydrogen at the present time. Hydrogen research is entirely administered from the Office of Conservation and Renewable Energy, and is a small (and unimportant) program of about $1.5 M/yr. The Office of Energy Storage and Distribution (under Conservation and Renewable Energy) is supporting a small fuel cell program for use in transportation applications (via Lawrence Berkeley and Los Alamos National Laboratory), as is the Office of Transportation along with the Department of Transportation in a parallel program. Both these are aimed at the use of stream-reformed methanol in the fuel cell. In this connection, we must stress that ***all*** fuel cells as presently conceived can only consume hydrogen, and that all fuels for fuel cells must be transformed into hydrogen. For example, if a fossil or synthetic fuel such as coal, natural gas or methanol is used, it must be first converted into a suitable mixture of hydrogen and carbon oxides. For coal, this is effected by reaction with steam and oxygen. For methane and methanol, steam alone suffices.

In the interests of energy conservation and maintenance of the CO_2 level in the atmosphere, hydrogen is the inevitable future fuel. However, hydrogen and fuel cells will be natural partners: hydrogen can be used in fuel cells at 55% efficiency, whereas if burned in internal combustion engines it is no more efficient than gasoline. In this repect, the hydrogen-fuel cell combination is a high-quality energy vector. Methanol converted and used in the fuel cell will lead to growth of atmospheric CO_2, whereas, as I pointed out in my testimony, hydrogen can be made from coal without increasing the atmospheric CO_2 burden.

In the long term, fuel cells and hydrogen must be linked. However, the major U.S. fuel cell program is under the Office of Fossil Energy. Fossil is not interested in synthetic hydrogen from coal, and hence the important hydrogen-fuel cell tie is not being made. The cheapest source of hydrogen will be coal, not solar energy. Hence, the Office of Fossil Energy must be made to take hydrogen seriously. This policy should be of prime long-term importance.

2. DOE support is still needed in the fuel cell area, especially for the more advanced technologies which will become available commercially only after the year 2000. Even though the principals are now known, detailed design and long-term testing is required before the designs become commercially and economically credible. For hydrogen, see above: strong support on fossil-origin hydrogen is required since ***nothing*** is being done today.

3. DOE's transfer of fuel cell technology, via funded developers such as International Fuel Cells, the Institute of Gas Technology and its collaborators, and Energy Research Corporation, as well as to (and via) the Electric Power Research Institute, has been effective. So indeed has technology transfer to Japanese developers. For hydrogen, however, much needs to be done, as indicated under (2) and 3).

4. No. Certainly not for fuel cell technology. DOE has proved to be extremely valuable in maintaining research and development programs. We should realize that the Japanese national fuel cell program is as large as that in the U.S., and it includes 50% cost-share from the large corporations. That is not happening in the United States. For hydrogen, our program is woefully inadequate. West Germany plans to spend $650 M over four years on renewable resources, of which hydrogen is a large part. We need to spend money on the development of coal-based (fossil) hydrogen, and integrate DOE's fuel cell and hydrogen programs.

University of Hawaii at Manoa

Hawaii Natural Energy Institute
Holmes Hall 246 • 2540 Dole Street • Honolulu, Hawaii 96822

November 13, 1987

The Honorable Wendell H. Ford
United States Senate
Chairman, Subcommittee on
Energy Research and Development
SH-312 Hart Senate Office Bldg.
Washington, D.C. 20510-6150

Dear Senator Ford:

I am pleased to respond to Senator James McClure's questions in follow-up to your hearing on S. 1294/5/6. We appreciate your interest and support on these bills of great importance to our nation's future.

Aloha,

Patrick K. Takahashi
Director

PKT:sy

Encls: Response to questions
HNEI brochure

cc: S. Matsunaga
J. McClure

1. Do you feel that the Department of Energy is effective in coordinating its research (in fuel cells and hydrogen) to be responsive to commercial interests?

   The Department of Defense and NASA have significantly expanded their hydrogen programs over the past few years. The USDOE does support some fundamental work in these areas and has initiated a commendable program in hydrogen from renewable energy. However, a far more comprehensive program as outlined in S. 1294/5/6 can materially enhance our strategic capability over time.

2. Do you feel that DOE's programs advance the research and development to a sufficient degree of maturity to enable the private sector to make use of DOE's work? Or would you rather see DOE take the work into a more advanced stage?

   The USDOE needs to take a much more vigorous and comprehensive approach to advancing R&D in these fields.

3. Do you feel that DOE is doing a good job in transferring these technologies to the private sector? What improvements would you suggest in the area of technology transfer?

   No. We lost our lead in fuel cells to Japan a few years ago, and might well fall behind to Japan, West Germany, Canada and the USSR if we don't pick up the effort in hydrogen systems. While DOD and NASA will be spending $3 billion to develop the National Aerospace plane, and have testified before various congressional panels about their concern about the prospects of being able to obtain cost effective hydrogen, the USDOE, for reasons that mystify me, does not seem to care. However, for technology transfer to occur, there needs to be a critical mass of transferable technoogies. This is one area where a major upgrade can be instituted to prepare for tech transfer as the turn of the century approaches.

4. Is there any sentiment out in the private sector that, because DOE focuses primarily on long-term, high-risk research and development, that most of DOE's work is useless? Or do you feel that their work is meaningful and beneficial to the overall adavancement of fuel cell and hydrogen technologies?

   There is this general sentiment, but much of this feeling derives from an overall dissatisfaction with regards to the administration's attitude about the non-importance of non-nuclear energy as a research responsibility of the Federal government. The officials in the Renewable Energy and Conservation assistant secretariat care and would like to be able to do a lot more. However, the White House and OMR have methodically and tragically emasculated our world leadership capability. The core of expertise and fundamental zeal, however, remains within the USDOE and can be re-activated should there be a switch in philosophy of the administration, another energy crisis or a strong show of support from Congress.

UNIVERSITY OF MIAMI

November 9, 1987

Honorable Wendell H. Ford
Chairman, Subcommittee on
Energy Research and Development
United States Senate
Washington, DC 20510-6150

Dear Mr. Ford:

Thank you very much for your letter on November 1987, in connection with my testimony on 23 September 1987 on S. 1294, S. 1295, and S. 1296, regarding fuel cell research and development, fuel cell utilization policy, and hydrogen research and development. Please find enclosed my answers to the questions submitted by Senator McClure.

With best regards I am,

Sincerely yours,

T. Nejat Veziroglu
Director

Enclosure

TNV/as

Clean Energy Research Institute
College of Engineering
P.O. Box 248294
Coral Gables, Florida 33124
(305) 284-4666

9/23/87 Hearing on Fuel Cells and Hydrogen Research

Answers to Questions Submitted by Senator McClure

by

T. Nejat Veziroglu
Director, Clean Energy Research Institute
University of Miami

Question 1: Do you feel that the Department of Energy is effective in coordinating its research (in fuel cells and hydrogen) to be responsive to commercial interests?

Answer 1: I do not feel that the Department of Energy DOE is effective in coordinating its research in fuel cells and hydrogen energy to be responsive to commercial interests. It must establish a separate division on the hydrogen energy system, and increase its budget substantially for research and development in the hydrogen energy area, including fuel cells.

Question 2: Do you feel that DOE's programs advance the research and development to a sufficient degree of maturity to enable the private sector to make use of DOE's work? Or would you rather see DOE take the work into a more advanced state?

Answer 2: I feel that DOE should work together and in harmony with the private sector in order to bring to a sufficient degree of maturity of the research and development of fuel cells and hydrogen energy. The R & D work funded presently is not of sufficient magnitude to meet the needs of the industry and the nation.

Question 3: Do you feel that DOE is doing a good job in transferring these technologies to the private sector? What improvements would you suggest in the area of technology transfer?

Answer 3: Before DOE can transfer technologies to the private sectors, it must initiate research and development work covering many aspects of fuel cells and hydrogen energy. It is therefore essential that they should increase funding of research and development work in fuel cells and hydrogen energy.

Question 4: Is there any sentiment out in the private sector that, because DOE focuses primarily on long-term, high-risk research and development, that most of DOE's work is useless? Or do you feel that their work is meaningful and beneficial to the overall advancement of fuel cell and hydrogen technologies?

(Cont. 3rd page)

Answer 4: I feel that DOE is spending too much money on fusion research and coal research. Fusion research budget could be cut in half and the coal research should be terminated. Technology for coal gasification and liquefaction is mature. Germans and South Africans have been using it since the Second World War. Part of the funding saved in this way could be used for fuel cell and hydrogen R & D work, and the rest should be eliminated to reduce the total DOE budget.

SOLAR REACTOR TECHNOLOGIES
2666 Tigertail Avenue • Suite 115 • Miami, FL 33133 (305) 854-2668 • FAX (305) 854 2739

10 December 1987

The Honorable Wendell H. Ford
U.S. Senator and Chairman,
Subcommittee on Energy Research and Development
Committee on Energy and Natural Resources
United States Senate
Washington, DC 20510-6150

Dear Senator Ford:

I enclose herewith replies to the four questions you sent me in your correspondence of 2 November 1987, provided by Senator McClure pursuant to my testimony of 23 September 1987 before your Senate Subcommittee in reference to S. 1294, S. 12395, and S. 1296.

I was very pleased and gratified to be included in the very distinguished panel convened at your hearing, and would be glad to provide additional testimony in future on these and other energy-related matters should you require it of me.

Sincerely,

Peter W. Langhoff

Vice President of Research
Solar Reactor Technologies, Inc.

Professor of Chemistry
Indiana University, Bloomington

Reply of Peter W. Langhoff, Solar Reactor Technologies, Inc.,

to " Questions to Outside Witnesses"

9/23/87 Hearing on Fuel Cells and Hydrogen Research

1. DoE supports fuel cell technology development under the auspices of Fossil Fuel, Conservation and Renewable Energy, with a budget of approximately $40,000,000/year. The goal of this program is the high-efficiency (>50%) utilization of fossil reserves (coal and natural gas) employing fuel cells for the direct generation of electricity as an alternative to indirect generation of electricity using combustion-driven turbines or related mechanical devices. DoE response to commercial interests - the fossil-fuel community in this case - is satisfactory. DoE basic research in fuel cells unrelated to fossil-fuel interests is carried out under the auspices of Energy Storage and Distribution, Conservation and Renewable Energy, with a FY 86 budget of approximately $670,000. Although there is some response to the commercial interests of a small number of corporate players (G.E, Dow, G.M.) directly engaged in such research, the budget is so small that the question is really moot. It seems, therefore, that DoE fuel-cell research and development is highly focused on fossil-fuel interests, or Conservation, in which area the Department is generally responsive to commercial interests. There is, however, virtually no meaningful DoE program presently in place on fuel-cells research and development that would qualify under the heading of Renewable Energy which could be configured in some way to be responsive to commercial interests.

DoE research and development on Hydrogen Energy is coordinated by the DoE Hydrogen Energy Coordinating Committee, with an overall program budget in FY 86 of $21,200,000. Of this amount $3,300,000 is expended on Mission Related projects, such as economical production, storage and distribution of hydrogen, with the rest expended on peripheral Nonmission Related research. The major program in the latter category is largely Basis Energy Science research in photochemistry and electrochemistry, with a FY 87 budget of $14,200,000. Although the latter program supports generally high-quality basic research, no attempt is made to be responsive to any commercial interests whatsoever. Of the Mission Related programs, there is modest response to commercial interests (Westinghouse, Battelle) directly involved in the research programs.

In summary of my answer to this first question, DoE expends approximately $60,000,000/year on fuel-cell and hydrogen-energy research, with the major share in support of efficient fossil-fuel utilization. Response to commercial fossil-fuel interests is generally good. Conspicuously absent, however, is any meaningful DoE Renewable Energy program on fuel cells and hydrogen energy, involving solar energy, for example, that could be responsive to commercial interests in the near term.

2. Much of the research and development DoE supports on fuel cell and hydrogen energy is of significant benefit to particular segments of the private sector. I would be glad to provide a detail review of this aspect of their programs, if requested, from the perspective of my own interests or from that of the small and large business communities more generally. Only a limited number of DoE programs in fuel cell and hydrogen energy research and development should be taken forward by DoE to more advanced stages, however, as indicated in the following remarks.

3. It is in my view highly appropriate for DoE to attempt technology transfer into the private sector when acting in close collaboration with private and other public players, such as small and large technology companies, public utilities, and possibly academia. An excellent example of the benefits of such collaborative ventures are the solar energy electrical power generating facilities presently operating in California, Georgia, and elsewhere which have been brought on line though cooperative ventures including DoE in various ways. The National Science Foundation is presently considering the establishment of Science and Technology Centers involving such cooperative ventures in the hopes of aiding technology transfer to the private sector. Such DoE ventures should be highly mission oriented in order to provide a suitable technical focus for such an arrangement. The materials laboratories and other facilities now in place largely in academia, and some of the national laboratories, are so oriented as to have little relevance to technology transfer.

4. DoE sponsored research on fuel cells and hydrogen energy is certainly meaningful and beneficial to these technologies, particularly as relates to efficient use of fossil fuels. There is a large and important research and technology development component missing, however, in the specific area of Renewable Energy. As indicated in my remarks under (1) above, DoE presently has no meaningful program in fuel cells and hydrogen energy that involves renewable energy sources. Particularly conspicuous is the absence of DoE support of solar energy programs that would have near-term benefit to the private sector and to the country in general. It is my understanding and hope that S. 1293, 1294, and 1295 will address this particular omission.

Material in the foregoing remarks has been adopted from (i) Hydrogen Energy Coordinating Committee Annual Report-Summary of DoE Hydrogen Programs for FY 1986, January, 1987, U.S. DoE, Conservation and Renewable Energy; (ii) DoE Fuel Cell Program Annual Report for FY 1986 1987, U.S. DoE, Conservation and Renewable Energy; (iii) Technology Base Research Project for Electrochemical Energy Storage, July 1987, Lawrence Berkeley Laboratory, LBL-23495

UNITED TECHNOLOGIES
PRATT&WHITNEY

1825 Eye St. N.W., Suite 700
Washington, D.C. 20006
202/785-7432

Mel Goodweather
Director, Government Relations

19 November 1987

The Honorable Wendell H. Ford
Chairman, Energy and Natural Resources
Subcommittee on Energy Research and Development
317 Dirksen Senate Office Building
Washington, DC 20510-6150

Dear Mr. Chairman:

Pratt & Whitney would like to thank you for giving us the opportunity of testifying before your Subcommittee on the issue of hydrogen research and development during the hearing on this subject on September 23 of this year, and we were pleased to receive the follow-up questions from Senator McClure, dated November 2, which were sent to our witness Mr. Richard Marshall.

After making a careful review of the questions and circulating them within Pratt & Whitney, we find that our company has had only minor contact with the Department of Energy and therefore we do not feel qualified to respond to Senator McClure's questions. However, we also circulated the questions to some of the other companies within United Technologies Corporation (UTC) to see whether other areas within UTC were in a better position to respond to the issues raised.

In this regard Mr. W. Podolny, President of United Technologies' International Fuel Cells Corporation (IFC), has indicated that IFC would be pleased to address the issues raised by Senator McClure and I have been informed that a letter to that effect has been sent under separate cover to the Subcommittee.

Once again I would like to thank you for the concern you and your Subcommittee have shown in an area which remains of interest to Pratt & Whitney and we remain available to respond to additional questions if we are in a position to make a meaningful addition to the record.

Sincerely,

Mel Goodweather

cc: Richard Marshall

International Fuel Cells

195 Governors Highway
PO Box 739
South Windsor
Connecticut 06074

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November 17, 1987

The Honorable Wendell H. Ford
Chairman, Energy and Natural Resources
Subcommittee on Energy Research and Development
Dirksen Senate Office Building - Room 317
Washington, DC 20510-6150

Dear Mr. Chairman:

We at International Fuel Cells Corporation (IFC), a subsidiary of United Technologies Corporation, welcome the opportunity to respond to the questions posed by Senator McClure and to go on record in support of legislation regarding fuel cell and hydrogen research and development.

IFC appreciates the support the Congress has provided fuel cell research and development over the years. It has been the Congress, and not the Administration, that has initiated the federal role in fuel cells. This Administration has consistently requested inadequate levels of funding -- if any request was made at all -- for work in phosphoric acid, molten carbonate or advanced concepts.

We do not believe DOE's fuel cell program advances the research and development to a sufficient degree of maturity to enable the private sector to make use of DOE's work. Present Administration policy does not account for the reality of the utility marketplace.

The reality is that the national benefits of new power generation technologies (the fuel cell being one) are not perceived as being critically important by utility regulators. They discourage utilities from purchasing equipment embodying new technologies by stipulating the utility's customers should not have to bear any part of the economic risk of introduction of new technology. In other words, the regulator will gladly accept the national benefit of new technology to lower energy consumption and improve the quality of the environment <u>but</u> only if the "new technology" equipment is certified and warranted by the manufacturer to have the same reliability, availability, maintainability, capital cost, and durability as equipment embodying proven technology matured over 30 to 50 years.

Because utilities are permitted to purchase new equipment only if it is of equivalent cost and maturity as current equipment, significant new technology (such as the fuel cell) can not be commercialized without strong active federal government help. Private investors find the very large cost of maturing equipment to such a high level of acceptability, especially when there is no strong enunciated market "pull" by the utilities or regulators.

Facsimile (203) 727-2319 TWX 710-425-0137 Telex 681-3166

International Fuel Cells

The Honorable Wendell H. Ford - 2- November 17, 1987

Unfortunately, the policy espoused by the present Administration ensures little or no technology will be commercialized. It is their stated policy to not participate at all in the maturing of technology and in fact, to stop all support of a technology as soon as "proof of principle" is established.

Future funding requests for fuel cell research and development must reflect a realization that the highest risk is at the post-proof of concept stage. Budget requests of $5 million for all fuel cell activities will not provide the country with what the Congress and the Administration has indicated it wants -- a viable, competitive fuel cell manufacturing capability.

Very truly yours,

INTERNATIONAL FUEL CELLS CORPORATION

William H. Podolny
Chairman

/dd