

## AN ASSESSMENT OF THE GOVERNMENT LIQUID HYDROGEN REQUIREMENTS FOR THE 1995 - 2005 TIME FRAME

### PURPOSE

The purpose of this report is to present the results of a government study of long range liquid hydrogen (LH2) requirements for the time period of 1995 through the year 2005. The information in this report will be used to determine LH2 acquisition strategies to assure future availability of LH2 to support the variety of government programs as proposed.

### SCOPE

The report reflects projected government LH2 consumption patterns and is presented in geographical as well as programmatic aspects. In addition, current LH2 production levels and the influence of the commercial marketplace is included based on data provided from a NASA/KSC contracted study with SRI International.

### AUTHORITY

The Kennedy Space Center (KSC) is chartered to manage LH2 in support of all NASA programs and other government agency programs as prescribed by procurement regulations and mutual agreements.

### INTRODUCTION

To assure an adequate supply of LH2 is available in support of various programs, it is imperative a long range projection of LH2 requirements be developed and maintained. This information is vital in the planning for necessary procurement actions and assuring adequate industry lead time to acquiring the necessary production and distribution capabilities.

### STUDY APPROACH

A number of personnel were contacted representing various organizations having knowledge of potential LH2 needs in terms of technical aspects, program guidelines, schedules or other useful data to assemble consumption projections. It was predetermined that it would not be possible to guarantee LH2 amounts in specified time frames due to the typical dynamic behavior of program changes experienced from budget considerations and policy decisions. Optimistic as well as pessimistic projections were provided. The optimistic projection represents the LH2 requirements to current known schedules and contemplated projects being approved as currently proposed by the respective project office. The pessimistic projection is simply an arbitrary lower estimate on the part of the data source. Specific explanations are provided in the text.

The charting (exhibits) shows LH2 projections in tons per day (TPD) which equates to 730,000 pounds on an annual basis. Data was normalized on an annual basis. "Peaks" and "valleys" in site specific daily or monthly demands, although a very significant logistics concern, were not considered in this study.

## REPORT FORMAT

The report content is structured in the following manner:

### Program/Project Discussion

Each specific program or project is discussed regarding its scope, technical aspects, assumptions, method of data derivation, and scheduling information.

### Data Display

Explanations are provided on the methods selected for displaying and summarizing the data.

### Exhibit Discussion

A discussion is provided for each exhibit to orient the reader with the chart data.

### Concluding Observations

## PROGRAM/PROJECT DISCUSSION

### KENNEDY SPACE CENTER

The LH2 requirements to support the space vehicle launch activity at KSC include the STS, Shuttle-C, and ALS programs plus the upper stage Centaur used with the Titan and Atlas vehicles at CCAFS.

Space Shuttle -- The projected launch rate is about 14 per year. Some indications are that this could be a mix of 11 STS and 3 Shuttle-C. According to MSFC a two engine and three engine version of the Shuttle-C is under consideration with preference for the three engine configuration. This study uses the three engine version thus the LH2 needs are essentially the same as STS for purposes of this study. In the outer years a rate of 14 STS and 4 Shuttle-C was used based on the February 1990 "Option 5 Manifest."

Based on the average consumption for STS flights 1 through 28R (30 launches) a quantity of 319,000 pounds of LH2/launch is used. Complex 39A and B storage tank combined annual boiloff loss is 216,000 pounds. About 20,000 pounds of LH2 per year is consumed for other support. A factor of 14% is used to account for losses due to transfer into KSC storage as delivered by trailer from the production source.

Centaur -- The Atlas/Centaur launch rate used is 4 per year. The Titan/Centaur rate is 4 per year.

A base support of 3,500 pounds/month and a launch quantity of 14,000 pounds are experienced for the Atlas/Centaur program; the similar quantities for the Titan IV program are 7,000 pounds/month and 23,000 pounds per launch. Adjusting for losses the total annual Centaur projection is 312,000 pounds.

Advanced Launch System -- For a programmatic discussion see the ALS program write-up. The reference vehicle (110K payload) with ten 580,000 pound thrust engines is used.

Assumption was made that the ALS would require two new launch pads at CCAFS or KSC. Each pad would require two 1.5 million gallon LH2 tanks. Initiation of tank test/fill in 1999 with the first launch in the year 2000. The LH2 on board quantity (OBQ) for the core is the same as the booster (221,400 pounds each). Using STS experience factors, the average consumption per vehicle flow is calculated at 797,000 pounds.

Pad tank loading loss is 14%. Total LH2 needed to purchase per launch is therefore 908,580 pounds. For this study 910,000 pounds is used.

Experience shows a 0.25 factor for pad tank annual boiloff including transfer/filling losses. Therefore this loss is calculated as 885,000 pounds/year (4 tanks). This value would be constant for each year. The launch rate (traffic model) is taken from a July 1989 manifest and slipped according to an April 1990 program review presentation, using 2 per year followed by 4 per year in the initial part of the program.

## STENNIS SPACE CENTER

The LH2 requirements to support SSC include the on-going SSME testing for Space Shuttle with the addition of the ALS program involving thrust chamber, gas generator, turbopump assembly and main engine testing.

SSME -- The SSME testing program (requalification) involves engine firings for a variety of test runs such as 1.5 seconds, 250 seconds, or 520 seconds duration. Usage per test is 50,000 pounds plus 147 pounds per second of test. The ongoing program is an "8 test" per month schedule. The quantity was calculated at 10,731,000 pounds per year and is used as a constant requirement for purposes of this study.

ALS -- The product requirement for the proposed ALS program is dependent on the engine design chosen and amount of developmental work required, associated with the engine and its subcomponents. The flow rates and planned durations are normally known. Due to the nature of a hardware development program involving a sophisticated cryogenically fueled space vehicle engine actual test durations and number of tests needed are simply unpredictable. Using an experience base of engine development history and knowledge of the proposed engine basic performance characteristics a range of projections was however developed.

The STME engine proposed is a 580,000 pound thrust machine burning LH2 at the rate of 190 pounds per second. The same engine would be used in the Core vehicle as well as the Booster. First engine firings are planned for 1997 (ALDP Program Review, April 1990). Test durations include 180, 250, 620, and 780 second runs. Significant requirements to support component work assumed to start in 1996 based on the slippage in ALS timetable. The data is summarized in the following table. It is noted the SSC optimistic projection in 2002-2005 includes follow-on advanced work.

(K pounds typical)

	<u>Optimistic</u>	<u>Pessimistic</u>
1995	---	---
1996	15,000	7,545
1997	21,915	10,957
1998	57,040	28,520
1999	41,950	20,975
2000	50,340	25,170
2001	41,778	20,889

2002	55,940	11,970
2003	55,940	11,970
2004	55,940	11,970
2005	55,940	11,970

## OTHER NASA CENTERS

MSFC -- Estimated average is 350,000 pounds per quarter for the hydrogen/oxygen propulsion development program.

LaRC -- The NASP-GTE engine development program may require upwards of 442,400 pounds of hydrogen per year at this location in the 1995-1996 timeframe.

LeRC -- On site requirements are estimated at 255,000 pounds per year in support of the Cryogenic Fluids Technology Office projects, testing at the Plumbrook K site facility and Lunar/Mars related projects. Off site (contractors now unknown) needs are forecasted to be in the range of 125,000 pounds per year in support of the potential Lunar/Mars technology effort.

JSC -- Tests at the Thermochemical Test Area on the Shuttle Power Reactant Storage system and Shuttle LH2 recirculation pump acceptance after refurbishment is estimated at 12,000 pounds per year.

WSTF -- In consideration of Space Station and the proposed Lunar/Mars initiative the activities at the White Sands Test Facilities (test stands 302, 401, 404 and 405) could become substantial. Requirements would be for development and qualification of Space Transfer Vehicle, Lunar Excursion Vehicle, and Attitude Control System engines in a simulated space environment. The following estimate is provided:

(in K pounds)

1995	500
1996	1,000
1997	6,000 to 10,000
1998	6,000 to 10,000
1999	6,000 to 10,000
2000	3,000 to 5,000
2001	1,000
2002	500
2003	500
2004	500
2005	500

DFRF -- A Structural Test Facility, using LH2, to perform thermal related tests on advanced airframe configurations is planned to be built by 1993/94. The initial work will be in support of the X-30 and NASP programs. For the timeframe of 1995 to 1999 the LH2 estimate is 300,000 pounds per year, and for 2000 through 2005, 150,000 pounds per year in support of potential advanced space vehicle structures research.

**VANDENBERG AFB**

Centaur -- Titan IV/Centaur launches are planned at VAFB. Three launches per year of the Titan IV are planned however only one is planned to have the Centaur upper stage. Based on experience of Centaur usage at CCAFS the VAFB estimate is 126,000 pounds per year.

ALS -- The ALS traffic model of July 1989 shows a normal mission scenario of 2 launches per year in 1998 and 1999 building to 3 to 4 in 2000 and beyond for the Western Test Range (WTR). In view of the program change (April 1990) with the first launch in early 2000 (presumably from KSC) the WTR schedule is shifted accordingly. The same pad configuration is assumed as that planned at KSC. Tank fill is assumed in 2000 and 2 flights per year in 2001 and 2002 building to 4 in 2003 through 2005. See KSC ALS discussion for detail derivations.

Summary of Data (K pounds) Total for VAFB

1995	126
1996	126
1997	126
1998	126
1999	126
2000	569
2001	2,459
2002	2,459
2003	4,349
2004	4,349
2005	4,349

**EDWARDS AFB**

Other than the DFRF, previously identified, two other locations at EAFB in the planning for LH2 use are the Astronautics Laboratory and the Ground Support System to support the X-30 at the Air Force Flight Test Center (AFFTC). (See also the HALE Program.)

Astro Lab -- The 2A Facility will be used to test the Thrust Chamber Assembly and Gas Generator for advanced propulsion concepts. The 3,800 gallon run tank and 28,000 gallon storage tank will be used for LH2. Plans called for 340,000 to 1,220,000 pounds of LH2 per year prior to 1994. In view of ALS programmatic changes it appears the requirement will slip into 1995/1996 timeframe. An annual average of 600,000 pounds was used in this study.

AFFTC -- The LH2 Ground Support System size will depend on the vehicle configuration selected. Under consideration is what is known as the 1X payload and the 4X payload. In the case of the 1X there are two 900,000 gallon tanks proposed to support LH2 requirements. For

the 4X two 1,500,000 gallon tanks are proposed. The on-board quantity for 1X is about 120,000 pounds and for the 4X about 200,000 pounds. For this study activation of the ground system was assumed for 1996 with the first flight in 1997. To determine the effect on LH2 requirements during 1999 through 2002 a low and high range were picked to establish the range magnitude. The range looked at is for a 1X at 20 flights per year over 4 years at 165,000 pounds per flight (allowing for losses) which equated to 3,300,000 pounds per year. The other is for a 4X at 40 flights per year over 4 years at 280,000 pounds per flight, equating to 10,200,000 pounds per year. For 2003 through 2005 a range of 825,000 to 2,800,000 pounds of LH2 was selected (no data source) representing 5 to 10 operational flights per year (1X and 4X respectively).

## DEPARTMENT OF ENERGY

The DOE has a number of research plants and laboratories engaged in projects requiring bulk gaseous hydrogen (delivered as liquid) and some direct liquid requirements. The following summarizes these requirements and locations.

### West Coast

Los Alamos, NM

The most significant demand for LH2 at this location is in support of the proposed Ground Test Accelerator Program. It is anticipated needs will start in 1991 during initial tests of the 28,000 gallon storage system but will climb to one to three million pounds per year by the mid 1990's. Optimistic longevity of the program is 1999.

Stanford, CA

Support at the high energy lab has historically run at 14,000 to 27,000 pounds of LH2 per year and is anticipated to continue at this level.

### East Coast

Pinellas Plant, FL

Although LH2 projections are in the range of 10,000 pounds per year for operation of the furnaces for manufacturing electronic piece parts, the historical consumption has reached annual levels of 150,000 pounds.

Bettis Lab  
West Mifflin, PA

The materials technology project has had a small requirement for LH2 at about 1,000 pounds/year, but is expected to increase at a 5% rate/year through the time frame of this study.

Knolls Lab  
Schenectady, NY

The projection at this atomic power facility is 5,000 pounds/year.

Brookhaven Lab  
Long Island, NY

Usage for the high energy particle accelerator is estimated between 8,000 to 21,000 pounds per year.

## DEPARTMENT OF COMMERCE

A variety of projects involving slush hydrogen, thermal conductivity and heat transfer are conducted at the National Institute of Standards and Technology (NIST) in Boulder, Colorado. Overall requirements are about 7,000 pounds/year.

## GOVERNMENT CONTRACTOR LOCATIONS

Pratt & Whitney  
West Palm Beach, FL

Annual estimates are:

RL-10	110,000 pounds
SSME	200,000 pounds (1994-1997)
ALS	160,000 pounds (1994-1999)
	200,000 pounds (2000)
	100,000 pounds (2001-2005)
NASP	40,000 pounds (1994-1998)
	20,000 pounds (1999-2000)

Wyle Laboratories  
Norco, CA

A range of 180,000 to 266,000 pounds per year was used in this study.

General Dynamics  
San Diego, CA

A range of 105,000 to 195,000 pounds per year was used in this study.

Other locations and their annual estimates (pounds) are as follows:

Aerojet Tech Systems Co.  
Sacramento, CA

30,000 - 70,000

Ball Aerospace  
Berthoud, CO

28,000

Martin Marietta  
Denver, CO

10,000

National Technical Systems  
Saugus, CA

0 - 10,000

Rockwell International  
Downey, CA

24,000

Rocketdyne  
Santa Susana, CA

100,000 - 200,000

## THE SEALAR PROGRAM

Called the Sea Launch and Recovery (SEALAR) vehicle, this system would be composed of two stages, each powered by a pressure-fed liquid propellant engine. The entire vehicle would be floated out to sea prior to lift-off. The stages would be recovered and refurbished. The 110 foot tall rocket first stage would be fueled with RP/LO2 and second stage LH2/LO2. The OBQ for LH2 is 22,000 pounds. First launch is planned for 1997/1998 (recent momentum on program could accelerate first full configuration vehicle test). Plans are to start with a launch per quarter building to six per month in eight years. Honolulu, San Diego, Galveston and Jacksonville are potential LH2 loading ports, with San Diego as most likely.

For this study it was assumed all LH2 requirements would be based out of San Diego at the following rate (30,000 pounds per flight was used):

	<u>Launches</u>	<u>Optimistic</u>	<u>Pessimistic</u>
1997	R&D	100,000	100,000
1998	4	120,000	120,000
1999	12	360,000	360,000
2000	21	630,000	630,000
2001	29	870,000	870,000
2002	38	1,140,000	870,000
2003	46	1,380,000	870,000
2004	55	1,650,000	870,000
2005	63	1,890,000	870,000

## THE HALE PROGRAM

Called the High-Altitude Long-Endurance (HALE) unmanned aircraft, this system is planned to provide a capability to operate for extended periods of time at very high altitudes to provide continuous reconnaissance, surveillance, communications, and targeting functions.

Each HALE aircraft flight would require 24,000 pounds of LH2. Endurance would be up to five days. R&D efforts are assumed for EAFB. Operational fueling sites are planned in Arizona, Nevada and Utah.

The operational capacity in the 2002 to 2005 timeframe is phenomenal with 43 aircraft servicing what is known as the inner line and 18 on the outer line. This schedule poses a significant demand on LH2 production and distribution. The following demand forecast was derived:

1994	10,000
1995	70,000
1996	130,000
1997	190,000

1998	250,000
1999	310,000
2000	320,000
2001	430,000
2002	500,000
2003	6,000,000
2004	6,000,000 to 50,000,000
2005	6,000,000 to 117,530,000

Assume 1994 through 2002 as requirements out of EAFB for developmental work and flight support until fueling sites are set up in other states.

### **THE THESEUS PROGRAM**

The Theseus is a long-range, very high altitude aircraft using fuel cell propulsion and capable of conducting worldwide chemistry, radiation, and dynamics experiments. It is planned that the aircraft would be usable by 1994/1995. The LH2 OBQ is 500 to 1,000 pounds. DFRF would probably be the test bed for development and testing, with operational flights out of government facilities (Wallops, KSC, National Science Foundation Balloon Facility in Texas, New Mexico, etc.).

Requirements are estimated at 100,000 pounds per year at DFRF during 1994-1995. 50,000 pounds per year is estimated out of the West Coast and the same from the East Coast for 1996 through 2005.

### **THE ADVANCED LAUNCH SYSTEM**

Air Force and NASA have identified needs in the late 1990s for a new space launch system for cargo transport which requires substantially improved reliability, operability and economy over current systems. The concept proposed is known as the Advanced Launch System (ALS) and is envisioned as a family of vehicles for a new generation launch system providing a capability for delivering a range of cargo sizes up to 220,000 pounds into low Earth orbit. The baseline family is a LO2/LH2 propelled vehicle using a 580,000 pound thrust (vacuum) engine in clusters according to vehicle sizing requirements. The model designated as ALS-80K is a lower range payload weight capability using a stage and one-half technique. The ALS-120K models use a parallel burn staging technique for heavier missions. The ALS-120K uses a core vehicle with an attached booster or boosters (ALS-300K).

This study uses the ALS-120K with a core and single booster, sometimes referred to as the baseline or reference vehicle. The vehicle LH2 tank size is essentially identical for the core and booster. The launch pad configuration varies among the studies but essentially predict the need for very large LH2 storage tanks (over one million gallons).

This study assumes two 1.5 million gallon tanks at each pad. The basis for this selection is twofold. First, it is understood from a well-known tank manufacturer that a 1.5 million gallon cryogenic sphere is about the sensible limit. The other factor is that with this size storage, sufficient product is on hand to accommodate a number of scrub turnarounds and launch two vehicles within two days of each other. Ullage, losses, and a thermal buffer are also accounted for in the chosen configuration. Additionally, the selection seems to fit the apparent DOD move towards a smaller vehicle with a high launch frequency and the NASA desire for a heavy lift launch vehicle (HLLV) but at a lower launch frequency.

## **OTHER POSSIBILITIES**

Arnold AFB, TN	The LH2 facility at Tullahoma may be activated (and expanded) to accommodate component testing.
Livermore Labs, CA	The hydrogen gas coil gun may demand LH2 for economies (as compared to gas recovery).
Hawaii Launch Site	Assume LH2 requirements would be met locally.
Japanese H-2	Under consideration for U.S. deployment in competition with other vehicles.
The Shuttle Z	A proposed Shuttle derived heavy lift vehicle requiring a new major engine development effort.
The Shuttle T	Due to limited cargo bay volume in the Shuttle C to accommodate in-space LH2 fueling, a tanker vehicle has been proposed. The Shuttle T concept would lift 43 metric tons of LH2 for each mission (lunar).
The SSX	The SSX launcher is a totally reusable rocket powered by the Pratt & Whitney RL-10 engine.
NASP	The requirements to support early testing of NASP engine configurations in terms of quantity and location is not yet defined but could be significant.
Delta Upper Stage	A high energy upper stage using LH2 is on the drawing boards. A CCAFS site has been proposed.

U.S. Hydrogen Energy Economy

Subject to pending legislation DOE and NASA may be requested to engage in R&D projects to promote non-fossil derived LH2 production and commercial aircraft utilization of LH2 as a fuel. Increased environmental concerns, fossil fuel limitations, and international competition for energy applications could inspire increased use of hydrogen.

Commercial Demand

The variety of goods and services using hydrogen (currently 9,000,000 tons annually) is anticipated to grow. The LH2 demand (currently 30,000 tons) is anticipated to grow accordingly due to its transport economics to support the commercial industries. The SRI study under KSC contract shows this growth pattern.

Miscellaneous

Further coordination is needed at some potential sites such as Colorado Springs, TRW at Redondo Beach, CA (OMV project) and programs such as the Naval Unmanned Aerial Vehicle (UAV) projects.

## DATA DISPLAY

Historically LH2 contracting has been split between what has been termed "West Coast" and "East Coast." The reason for this was simply due to the fact that production and major consuming sites were either concentrated in the California area or in the Mississippi/Alabama/Florida region. Today the West Coast contract provides LH2 services to California, New Mexico, and Colorado sites from a production plant near Los Angeles. The East Coast contract serves Texas, Mississippi, Alabama, Florida, Virginia, and Ohio consuming sites from a production source in New Orleans. Typically the major space program needs have concentrated at the engine test site in Mississippi (Stennis Space Center) and at the launch site in Florida (Kennedy Space Center). In view of these factors the data has been summarized and displayed as shown in the following exhibits.

## EXHIBIT DISCUSSION

Exhibit A -- This exhibit shows the LH2 projection in tons per day at the Kennedy Space Center. The Shuttle launch requirements are depicted in the range of 9 to 14 launches per year. The Shuttle launch rate of 14 could include 11 manned and 3 cargo configurations. The proposed Shuttle-C with LH2 payloads is shown at a launch rate of 4 per year. The influence of the Atlas Centaur and Titan Centaur launches from Cape Canaveral Air Force Station is shown at a total predicted rate of 8 per year. Assuming the first ALS launch is in the year 2000 the influence of a launch rate of 2 and then 4 per year is illustrated.

Exhibit B -- This exhibit shows the LH2 projection in tons per day at the Stennis Space Center. The Shuttle SSME engine testing is predicted at a constant level. The significant influence of the proposed ALS program is illustrated with the "high" number indicating the optimistic projection and the "low" as the pessimistic evaluation.

Currently the SSC requirements are being met by barging product from a nearby production plant. Shown is the current/planned capacity of this plant (NOLA). Based on SRI data for on-stream factors and plant utilization factors the production to support government and commercial requirements is plotted as a reference band. It is noted that about 30 TPD is routinely committed to commercial accounts.

Exhibit C -- This exhibit shows the tally of all government LH2 projections in tons per day for the using sites (sites east of the Mississippi River plus JSC) under a potential East Coast contract (or contracts).

The KSC data is the range of projections similarly shown in Exhibit A but in bar graph form. Likewise the SSC data (Exhibit B) is also shown in bar graph form. The "other" government data is in the range of 3 to 4 tons per day and includes MSFC, LeRC, LaRC, JSC, P&W, DOE, and Theseus.

As was shown in Exhibit B production capacity plots are also indicated. This includes the current producing sites in New Orleans, LA, Ashtabula, OH, and Niagara Falls, NY. Although there are production sources in Canada these are not only outside of the United States but were sized and built primarily for Northeast U.S. and Canadian commercial markets, and therefore are not considered significantly influential for government support. The effect however is shown by the North American East Coast capacity band. Also plotted is the SRI data on commercial demand through the year 2000.

Exhibit D -- This exhibit shows the tally of all government LH2 projections in tons per day for the using sites under a potential West Coast contract (or contracts).

For this exhibit the data is displayed in more of a programmatic form. The NASA needs include the numerous small consuming locations at the contractor sites at Aerojet, Rockwell, Wyle, General Dynamics, Ball, NTS, and Martin Marietta. Also in this category the requirements at DFRF and WSTF are included. The NASP is shown separately due to its potential significance and primary location at EAFB.

The other government requirements include VAFB, HALE, DOE, Department of Commerce (NIST), and SEALAR.

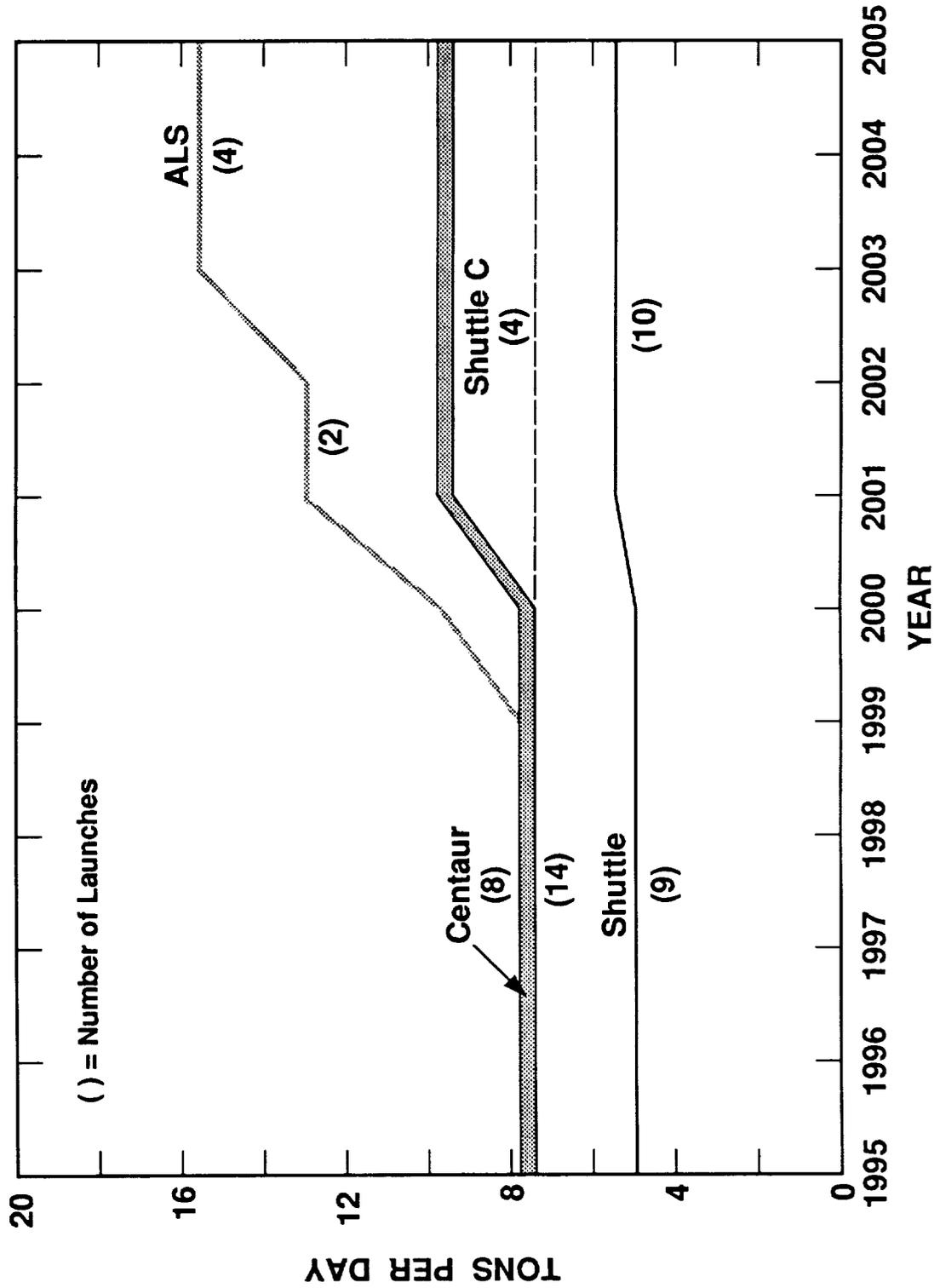
Also referenced are the LH2 production capacities and projected commercial demands. The producing plants include the existing facilities at Sacramento, CA and Ontario, CA.

Exhibit E -- This exhibit shows the total U. S. government LH2 projection in tons per day and illustrates the combination of Exhibit C (East Coast) and Exhibit D (West Coast) data. For reference purposes the total U. S. LH2 production capacity is shown as well as the total production in North America.

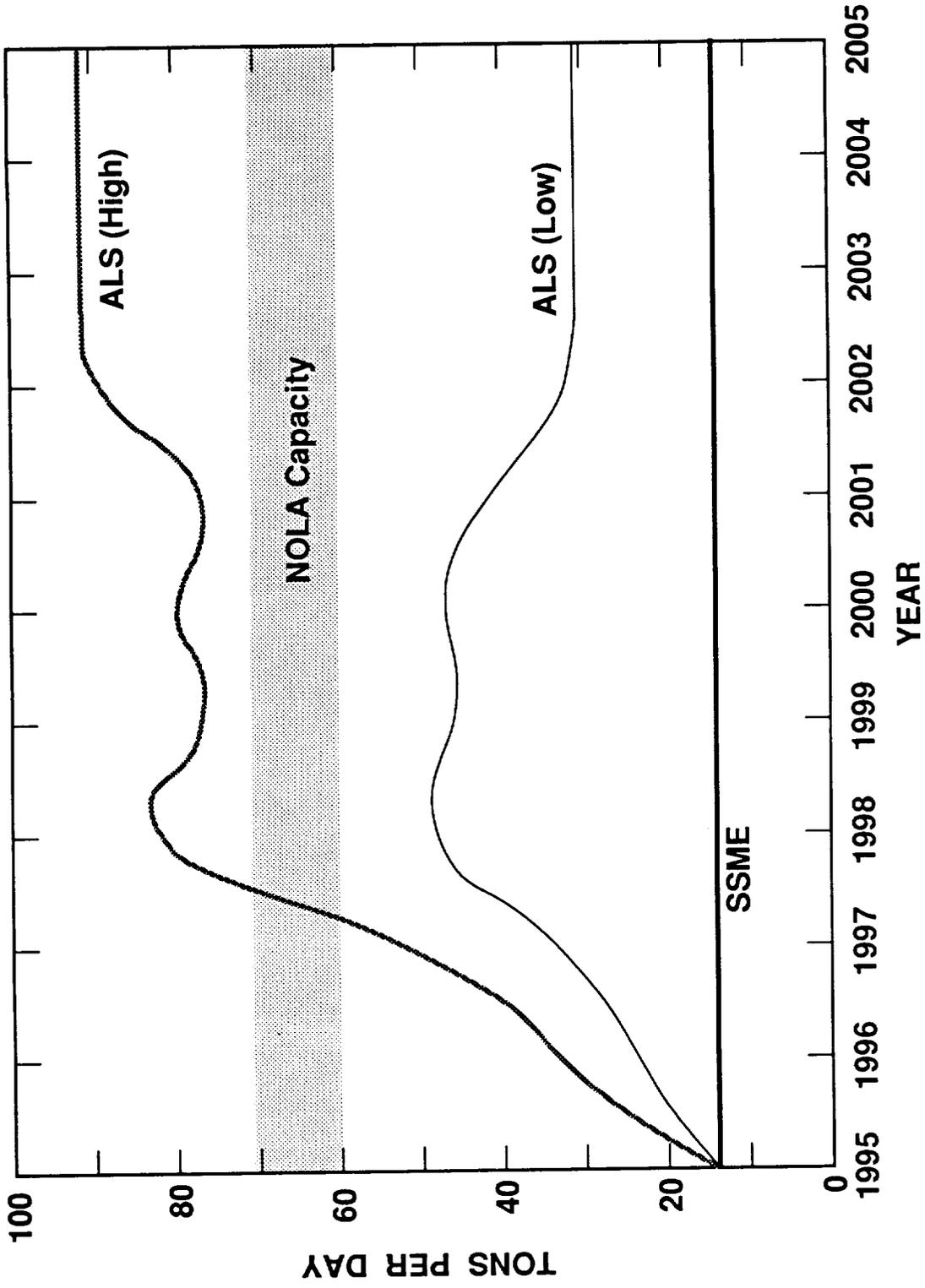
The term "high" was selected to show the tally of all optimistic projections and the "low" as the tally of all program projections on a reduced scale.

Exhibit F -- This exhibit is Exhibit E data with an overlay of commercial demand and its combined influence with the government projection.

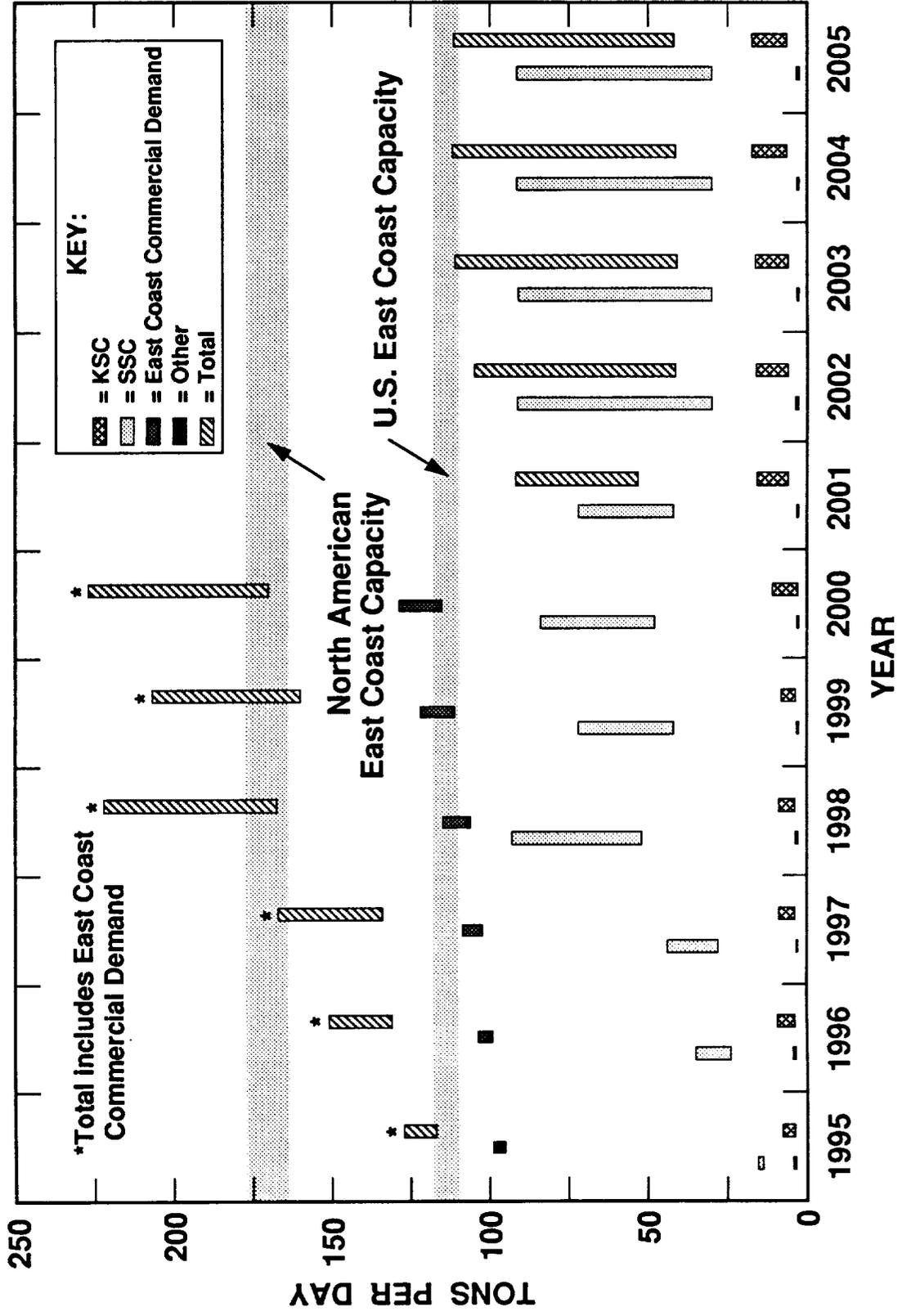
# EXHIBIT A KSC LH<sub>2</sub> PROJECTION



# EXHIBIT B SSC LH<sub>2</sub> PROJECTION

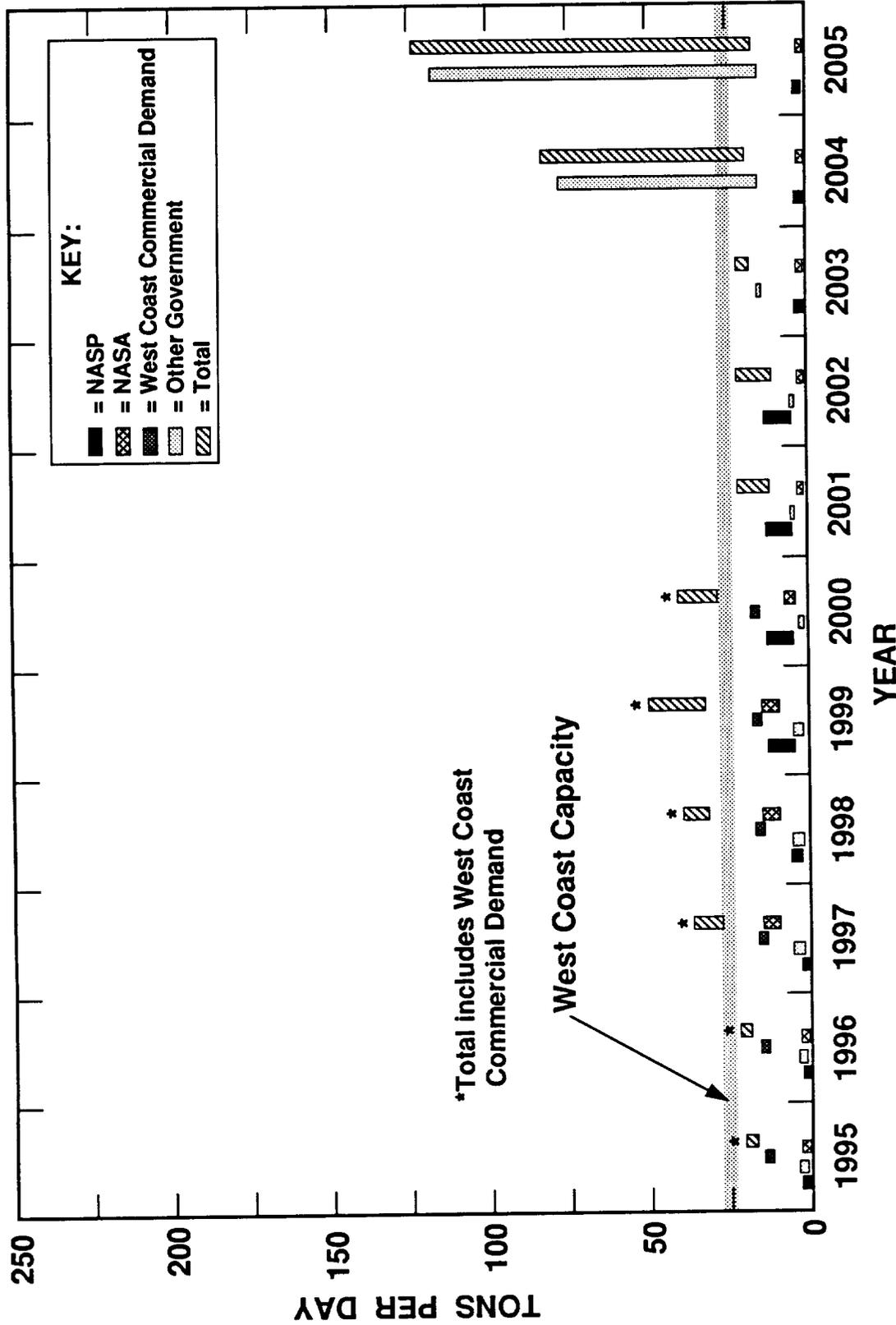


# EXHIBIT C GOVERNMENT EAST COAST LH<sub>2</sub> PROJECTION



SOURCES: NASA (government demand) and SRI International (all other data).

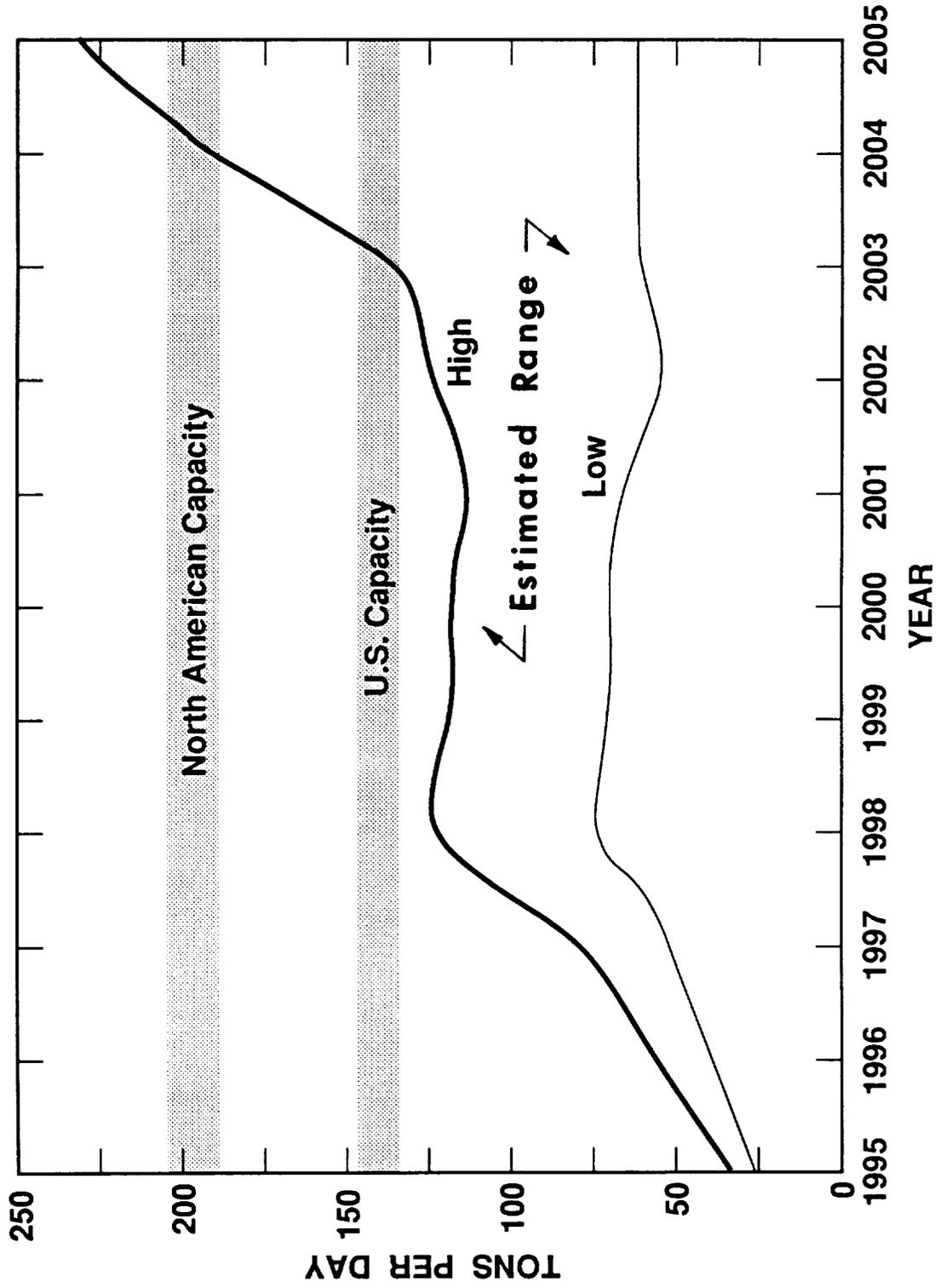
# EXHIBIT D GOVERNMENT WEST COAST LH<sub>2</sub> PROJECTION



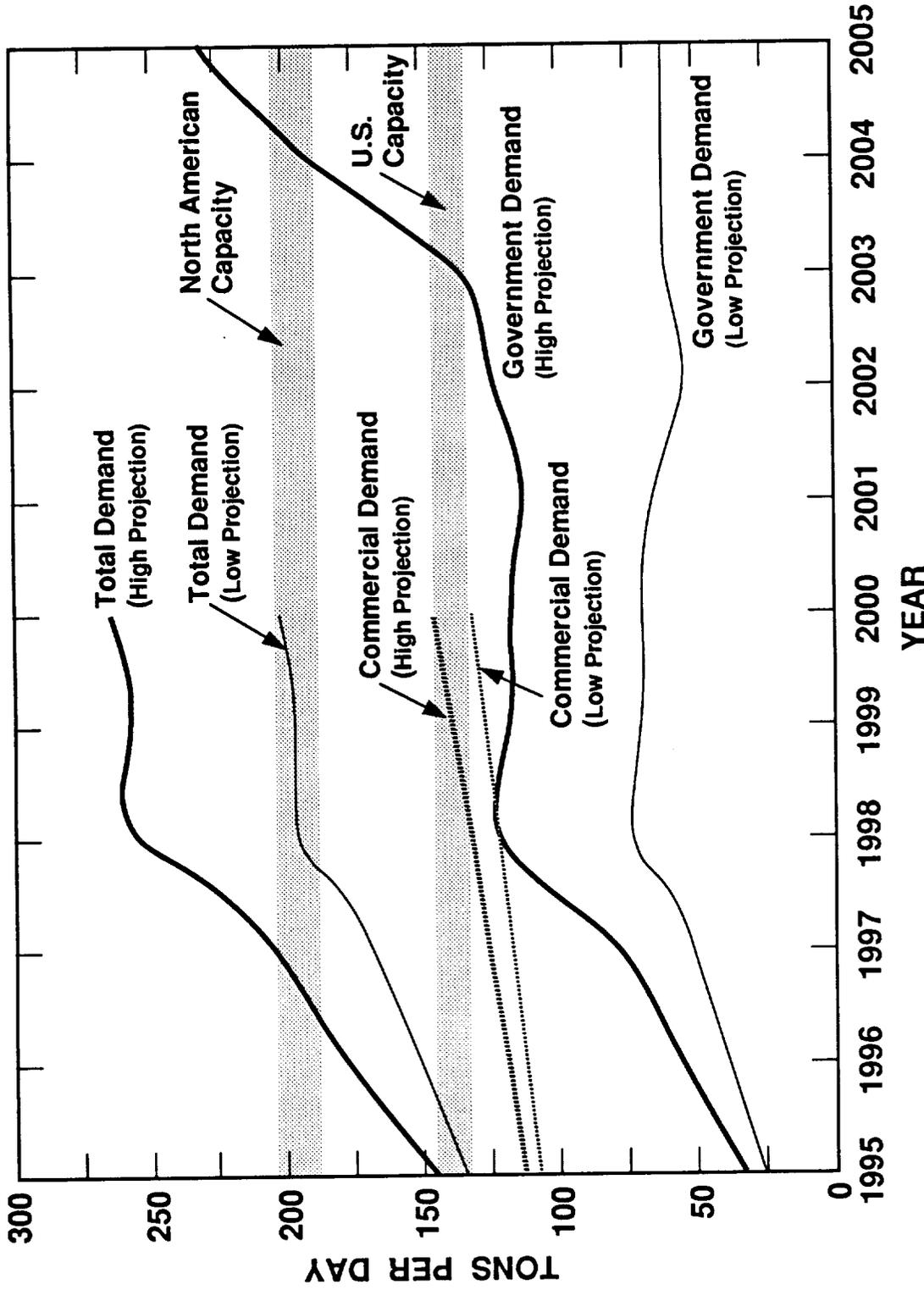
SOURCES: NASA (government demand) and SRI International (all other data).

SRI International

# EXHIBIT E GOVERNMENT TOTAL U.S. LH<sub>2</sub> PROJECTION



# EXHIBIT F TOTAL U.S. LH<sub>2</sub> PROJECTION



SOURCES: NASA (government demand) and SRI International (all other data).

SRI International

## **CONCLUDING OBSERVATIONS**

1. The ALS and HALE programs may represent the predominant government needs for LH2 in the long range. The extreme dispersion in predicted requirements for both of these programs however make the LH2 acquisition strategy selection difficult.
2. The data as assembled for this initial report clearly indicates a need for KSC constant program/project surveillance and close coordination with those organizations. Also clear is the need for KSC to monitor industry's plans for LH2 plant production and distribution expansion.
3. The uncertainty over the scope and location of the multitude of projects and programs make quantifying the demand for a critical fuel such as hydrogen extremely difficult. The need for a focused effort and continued close collaboration with all users and LH2 producers is evident.

## LH2 DEVELOPMENT STUDY DISTRIBUTION LIST

Wyle Laboratories, Inc.  
1841 Hillside Avenue  
Attn: Mr. D. L. McGowan  
Norco, CA 91760  
(714) 737-0871  
FAX-735-4030

The Aerospace Corporation  
2350 East El Segundo Boulevard  
Attn: Mr. Sherwin Lewis  
(213) 336-4512  
FAX-336-5833

The Aerospace Corporation  
P. O. Box 5068  
Attn: Mr. William Bartlett  
Vandenberg AFB, CA 93437  
FTS-785-0273  
FAX-785-2003

Tennessee Valley Authority  
Purchasing Department  
Attn: CST17W83/Mr. Roger Davis  
P. O. Box 11127  
Chattanooga, TN 37401  
(615) 751-7188  
FAX-751-8326

Sverdrup Technology, Inc.  
Stennis Space Center  
Attn: SSC Group/Mr. Charles R. Fox  
Bay St. Louis, MS 39529  
FTS-949-2250  
FAX-494-1925

San Antonio Air Logistics Center  
Attn: SFSP/Ms. Carmen Messer  
Kelly AFB, TX 78241-5000  
(512) 925-6195  
FAX-(512) 925-8048

Rockwell International Corporation  
Rocketdyne Division  
Attn: SS09/Mr. G. L. McGrath  
6633 Canoga Avenue  
Canoga Park, CA 91303  
FTS-981-5123  
FAX-N/A

Rockwell International  
Space Transportation Division  
Attn: AB80, Dept. 378, Div. 841/Mr. Paul Brandes  
12214 Lakewood Boulevard  
Downey, CA 90241  
FTS-985-2443  
FAX-N/A

Pratt & Whitney Aircraft  
P. O. Box 109600  
Attn: Ms. Cathy Roberson  
West Palm Beach, FL 33410-9600  
(407) 796-1175  
FAX-(407) 796-1273

National Technical Systems  
20988 West Golden Triangle Road  
Attn: Mr. Mick Hoff  
Saugus, CA 91350  
(805) 259-8184  
FAX-254-4814

National Aerospace Plane JPO  
AFSC/NAS/Capt. Mike Meerschaert  
Wright-Paterson AFB, OH 45433-6503  
(513) 255-1854  
FAX-255-1856

NASA  
NASA Headquarters  
Attn: MOK/Mr. Tim Seng  
Washington, DC 20546  
FTS-453-2578  
FAX-426-4483

NASA  
NASA Headquarters  
Attn: RP/Mr. William Escher  
Washington, DC 20546  
FTS-453-2858  
FAX-453-0608

NASA  
NASA Headquarters  
Attn: RP/Ms. Maria Lopez-Tellado  
Washington, DC 20546  
FTS-453-2856  
FAX-453-0608

NASA  
Langley Research Center  
Attn: 380/Ms. Suzanne Nelson  
Hampton, VA 23665-5225  
FTS-928-3568  
FAX-928-3800

NASA  
Stennis Space Center  
Attn: GA20/Mr. Gerald Pitalo  
Bay St. Louis, MS 30529  
FTS-494-1649  
FAX-494-1481

NASA  
Kennedy Space Center  
Attn: SI-PMS/Ms. Diane H. Holden  
Kennedy Space Center, FL 32899  
FTS-823-4957  
FAX-823-7369

NASA  
Kennedy Space Center  
Attn: SI-PMS/Mr. H. T. Everett  
Kennedy Space Center, FL 32899  
FTS-823-4957  
FAX-823-7369

NASA  
Kennedy Space Center  
Attn: SI-PMS/Mr. Leonard E. Nicholson  
Kennedy Space Center, FL 32899  
FTS-823-4957  
FAX-823-7369

NASA  
Kennedy Space Center  
Attn: DM-MED-41/Mr. Andy Rodriguez  
Kennedy Space Center, FL 32899  
FTS-823-3313

NASA  
Kennedy Space Center  
Attn: PT-FPO/Mr. William Dickinson  
Kennedy Space Center, FL 32899  
FTS-823-2780  
FAX-823-2217

NASA  
Kennedy Space Center  
Attn: PT-FLS/Mr. Tom Feaster  
Kennedy Space Center, FL 32899  
FTS-823-7705  
FAX-823-2217

NASA  
Marshall Space Flight Center  
Attn: CN23/Mr. Steve Cushman  
Huntsville, AL 35812  
FTS-824-5653  
FAX-824-1154

NASA  
Marshall Space Flight Center  
Attn: AB35/Mr. Aubrey Greer  
Huntsville, AL 35812  
FTS-824-7886  
FAX-824-4435

NASA  
Marshall Space Flight Center  
Attn: HA31/Mr. S. F. Morea  
Huntsville, AL 35812  
FTS-824-4082  
FAX-824-5890

NASA  
Marshall Space Flight Center  
Attn: HA41/Mr. Lawrence Wear  
Huntsville, AL 35812  
FTS-824-3215  
FAX-824-5890

NASA  
Marshall Space Flight Center  
Attn: SA24/Ms. Agnes Thomas  
Huntsville, AL 35812  
FTS-824-0819  
FAX-824-9190

NASA  
Stennis Space Center  
Attn: SA57/Mr. Boyce Mix  
Bay St. Louis, MS 39529  
FTS-494-2225  
FAX-494-3246

NASA  
Stennis Space Center  
Attn: SA25/Mr. Warren Swanson  
Bay St. Louis, MS 39529  
FTS-494-1655  
FAX-494-1481

NASA  
Lewis Research Center  
Attn: 500-220/Mr. Richard DeWitt  
21000 Brookpark Road  
Cleveland, OH 44135  
FTS-297-2601  
FAX-297-2629

NASA  
Lewis Research Center  
Attn: 500-220/Mr. G. P. Richter  
21000 Brookpark Road  
Cleveland, OH 44135  
FTS-297-2443  
FAX-294-5489 and 297-2629

NASA  
Lewis Research Center  
Attn: 500-200/Mr. Ned Hannum  
21000 Brookpark Road  
Cleveland, OH 44135  
FTS-297-2457  
FAX-297-2629

NASA  
Lewis Research Center  
Attn: 1720/Mr. Hugh McLaughlin  
21000 Brookpark Road  
Cleveland, OH 44135  
FTS-297-3080  
FAX-297-8000

NASA  
Johnson Space Center  
Attn: EP6/Mr. Richard Bozeman, Jr.  
Houston, TX 77058  
FTS-525-4516  
FAX-N/A

NASA  
Johnson Space Center  
Attn: BD3/Ms. Gloria Britton  
Houston, TX 77058  
FTS-525-4103  
FAX-525-6200

NASA  
Johnson Space Center  
Attn: MC5/Mr. Tom Gallagher  
Houston, TX 77058  
FTS-525-1418  
FAX-525-2080

NASA  
JSC White Sands Test Facility  
Attn: RE/Ms. Janet Reese  
P. O. Drawer MM  
Las Cruces, NM 88004  
FTS-572-5137  
FAX-572-5015

NASA  
JSC White Sands Test Facility  
Attn: RF/Mr. Frank Benz  
P. O. Drawer MM  
Las Cruces, NM 88004  
FTS-572-5722  
FAX-572-5260

NASA  
JSC White Sands Test Facility  
Attn: RD2/Mr. Irwin Smith  
P. O. Drawer MM  
Las Cruces, NM 88004  
FTS-572-5524  
FAX-572-5105

NASA  
Dryden Flight Research Facility  
Attn: EED/Mr. William Showers  
Box 273  
Edwards AFB, CA 93523-5000  
FTS-961-3368  
FAX-961-3567 and 961-3592

Los Alamos National Laboratories  
P. O. Box 1663  
Attn: F611/Dr. Fred Edeskuty  
Los Alamos, NM 87543  
FTS-843-4240  
FAX-843-3669 and 843-6937

General Dynamics  
Space Systems Division  
Attn: V2-7136/Ms. Pamela Mell  
P. O. Box 85990  
San Diego, CA 92138  
(619) 576-5271  
FAX-576-6674

EG&G Florida, Inc.  
P. O. Box 21267  
Attn: BOC-027/Mr. Robert Laws  
Kennedy Space Center, FL 32815  
(407) 867-2518  
FAX-823-2626

Dynamics Research Corporation  
Suite 802  
Attn: Mr. Robert Hulburt  
1755 Jefferson Davis Highway  
Arlington, VA 22202  
(703) 521-3812  
FAX-421-4123

Department of Energy  
1000 Independence Avenue  
Attn: CE-341/Dr. Michael Gurevich  
Washington, DC 20585  
FTS-896-6104  
FAX-896-4529

Department of Energy  
1000 Independence Avenue  
Attn: MA-422/Mr. James Cavanagh  
Washington, DC 20585  
FTS-896-8173  
FAX-586-8134

Chemical Engineering Center (NBS)  
325 Broadway Avenue  
Attn: Director/Mr. Jesse Hord  
Boulder, CO 80303-332  
FTS-320-5108  
FAX-320-3765

Bechtel National Incorporated  
Box 3965  
Attn: MS4526D35/Mr. Norman Stein  
San Francisco, CA 94119  
(415) 768-0233  
FAX-768-3588

Ball Aerospace  
19750 Weld County Road #7  
Attn: Mr. Jim Lewis  
Berthoud, CO 80513  
(303) 939-6111  
FAX-N/A

Naval Research Lab  
Code: 8305/Mr. Mike Melich  
Washington, DC 20375-5000  
(202) 767-6609

Aurora Flight Sciences Corporation  
3107 Colvin St.  
Attn: Dr. John S. Langford  
Alexandria, VA 22314  
(703) 823-0497  
FAX (703) 751-6947

Department of Energy  
1000 Independence Avenue  
Attn: CE-341/Dr. Michael Gurevich  
Washington, DC 20585  
FTS-896-6104  
FAX-896-4529

Department of Energy  
1000 Independence Avenue  
Attn: MA-422/Mr. James Cavanagh  
Washington, DC 20585  
FTS-896-8173  
FAX-586-8134

Chemical Engineering Center (NBS)  
325 Broadway Avenue  
Attn: Director/Mr. Jesse Hord  
Boulder, CO 80303-332  
FTS-320-5108  
FAX-320-3765

Bechtel National Incorporated  
Box 3965  
Attn: MS4526D35/Mr. Norman Stein  
San Francisco, CA 94119  
(415) 768-0233  
FAX-768-3588

Ball Aerospace  
19750 Weld County Road #7  
Attn: Mr. Jim Lewis  
Berthoud, CO 80513  
(303) 939-6111  
FAX-N/A

Naval Research Lab  
Code: 8305/Mr. Mike Melich  
Washington, DC 20375-5000  
(202) 767-6609

Aurora Flight Sciences Corporation  
3107 Colvin St.  
Attn: Dr. John S. Langford  
Alexandria, VA 22314  
(703) 823-0497  
FAX (703) 751-6947

Air Force Systems Command  
Attn: HQ SD/CLFRS/Capt. Kurt Held  
Los Angeles AFB, CA 90009-2960  
(213) 643-1262  
FAX-643-0338

Air Force Flight Test Center  
6510 Test Wing  
Attn: AFFTC/DORH/Mr. Kurt Buehler  
Edwards AFB, CA 93523  
(805) 277-3457  
FAX-277-0354

Air Force Astronautics Laboratory  
Attn: AL/TOAF/Ms. Margaret Whelan  
Edwards AFB, CA 93523-5000  
(805) 275-5084  
FAX-275-5084

Air Force Astronautics Laboratory  
Attn: AFAL/RKLB/Lt. Bao K. Nguyen  
Edwards AFB, CA 93523-5000  
(805) 275-5541  
FAX-275-5527

AF Wright Aeronautical Laboratories  
Attn: WRDC/TXAD/Mr. Charles Patterson  
Wright-Patterson AFB, OH 45433-5553  
(513) 255-5288  
FAX-255-4659

Aerojet Tech Systems Company  
Building 3308  
Attn: Dept. 9500/Mr. J. A. Bard  
P. O. Box 13222  
Sacramento, CA 95813  
(916) 355-3916  
FAX-N/A

Arnold Engineering Development Center  
Attn: 4960 ABS/LGS/MSGT Billy Adams  
Arnold AFB, TN 37389  
(615) 454-4413  
FAX-454-7330

Department of the Air Force  
Aerospace Test Group  
Attn: WSMC/SVO/Col David P. Schmarje  
Vandenberg AFB, CA 93437-6021  
(805) 866-0344

EG&G Vandenberg Operations Division  
Attn: Project Manager/Mr. Wayne Bithell  
P. O. Box 5338  
Vandenberg AFB, CA 93437  
(805) 865-0547

## DISTRIBUTION LIST

Airco Industrial Gases  
Attn: Mr. William Hoenigmann  
575 Mountain Avenue  
Murray Hill, NJ 07974

Air Products and Chemicals, Inc.  
Attn: Mr. Lawrence Belnoski  
P. O. Box 538  
Allentown, PA 18195

Air Products and Chemicals, Inc.  
Attn: Mr. Charles Anderson  
P. O. Box 538  
Allentown, PA 18195

Air Products and Chemicals, Inc.  
Attn: Ms. Joan Krichten  
P. O. Box 538  
Allentown, PA 18195

Aga Gas, Inc.  
P. O. Box 94737  
Cleveland, OH 44101-4734

Big Three Industries  
P. O. Box 3047  
Houston, TX 77253

Consolidation Coal Company  
4000 Brownsville Road  
Library, PA 15129

Electrolyser Corporation, Ltd.  
Attn: Dr. Alexander Stuart  
122 The West Mall  
Toronto, Ontario, Canada, M9C 1B9

Hoechst - Uhde Corporation  
560 Sylvan Avenue  
Englewood Cliffs, NJ 07632

Hydrogen, Inc.  
Attn: Mr. Larry Sloan  
P. O. Box 18-1236  
Casselberry, FL 32718

Liquid Air Corporation  
Attn: Mr. Robert Jennings  
2695 Villa Creek Drive, Suite 206  
Dallas, TX 75234

Liquid Air Corporation  
Attn: Mr. Claude Salama  
2121 N. California Boulevard  
Walnut Creek, CA 94596

Liquid Air Corporation  
Attn: Mr. Howard Percy  
2121 N. California Boulevard  
Walnut Creek, CA 94596

Liquid Carbonic I/M Corporation  
135 South LaSalle Street  
Chicago, IL 60603-5441

MG Industries  
P. O. Box 945  
Valley Forge, PA 19482

Solar Reactor Technologies  
2729 S.W. 22nd Avenue  
Miami, FL 33133

Union Carbide Corporation (Linde Division)  
Attn: Mr. Mario DeLucia  
39 Old Ridgebury Road, R3  
Danbury, CT 06817-0001

Union Carbide Corporation (Linde Division)  
Attn: Mr. Michael Kerr  
39 Old Ridgebury Road, R3  
Danbury, CT 06817-0001

Eagle Engineering, Inc.  
Attn: Mr. William Alford  
Tower Box 77  
2101 Executive Drive  
Hampton, VA 23666

Institute of Gas Technology  
Energy Development Center  
Attn: Mr. Christopher Blazek  
4201 W. 36th Street  
Chicago, IL 60632

Hydrogen Energy Systems  
Attn: Mr. Alessio Mezzina  
531 Surrey Place  
Oceanside, NY 11572

Cryogenic Industries, Inc.  
Attn: Mr. Alex Zeballos  
2321 S. Pullman Street  
Santa Ana, CA 92705-5506

S-R-B Industries  
Attn: Mr. E. L. Carr  
147 Meadow Glade  
San Antonio, TX 78227-1003

Astronautics Corporation of America  
Attn: Mr. Richard Foster  
5800 Cottage Grove Road  
Madison, WI 53716-1387

Electric Power Research Institute  
Attn: Dr. Ben Mehta  
3412 Hillview Avenue  
Palo Alto, CA 94303

Texas A&M University/CESHR  
Attn: Dr. John Appleby  
238 Wisenbaker ERC  
College Station, TX 77843

American Hydrogen Association  
Attn: Mr. Roy McAlister  
P. O. Box 15075  
Phoenix, AZ 85060

National Hydrogen Association  
Attn: Mr. Jeffrey Serfass  
1101 Connecticut Avenue N.W., Suite 910  
Washington, DC 20036

SRI International  
Attn: Ms. Barbara Heydom  
333 Ravenswood Avenue  
Menlo Park, CA 94025

University of Miami  
Clean Energy Research Institute  
Attn: Dr. T. Nejat Veziroglu  
Coral Gables, FL 33124

Solar Energy Research Institute  
Attn: Mr. William Hoagland  
1617 Cole Boulevard  
Golden, CO 80401

Air Force Flight Test Center  
Attn: Mr. Johnny Armstrong  
6510 Test Wing/DORH  
Edwards AFB, CA 93523

Mr. Peter Hoffman  
4104 Jefferson Street  
Hyattsville, MD 20781

Dr. Paul Maxwell  
2321 Rayburn Building  
Washington, DC 20515

Florida Solar Energy Center  
Attn: Dr. David Block  
300 State Road 401  
Cape Canaveral, FL 32920

NASA  
Kennedy Space Center  
Attn: SI/Mr. J. E. Rice  
Kennedy Space Center, FL 32899

NASA  
Kennedy Space Center  
Attn: SI/Mr. Marvin L. Jones  
Kennedy Space Center, FL 32899

NASA  
Kennedy Space Center  
Attn: SI-PRO/Mr. Wesley H. Dean  
Kennedy Space Center, FL 32899

NASA  
Kennedy Space Center  
Attn: DA/Mr. Andrew J. Pickett  
Kennedy Space Center, FL 32899

NASA  
Kennedy Space Center  
Attn: PT/Mr. William H. Rock  
Kennedy Space Center, FL 32899

NASA  
Kennedy Space Center  
Attn: DE/Mr. James D. Phillips  
Kennedy Space Center, FL 32899

NASA  
Kennedy Space Center  
Attn: TV-FSD/Mr. Robert G. Ward, Jr.  
Kennedy Space Center, FL 32899

NASA  
Kennedy Space Center  
Attn: DM-MED-4/Mr. William I. Moore  
Kennedy Space Center, FL 32899

NASA  
Kennedy Space Center  
Attn: DM-MED/Mr. Sterling W. Walker  
Kennedy Space Center, FL 32899

NASA  
Kennedy Space Center  
Attn: DE-PMO/Mr. Timothy M. Cross  
Kennedy Space Center, FL 32899

NASA  
Marshall Space Flight Center  
Attn: HA21/Mr. Craig E. Sumner  
Huntsville, AL 35812

NASA  
Lewis Research Center  
Attn: 500-200/Mr. Frank D. Berkopec  
21000 Brookpark Road, FL 32899  
Cleveland, OH 44135

NASA  
NASA Headquarters  
Attn: HS/Ms. Deborah A. Cresthull  
Washington, DC 20546

NASA  
NASA Headquarters  
Attn: QSO/Mr. Wayne R. Frazier  
Washington, DC 20546

NASA  
NASA Headquarters  
Attn: RP/Mr. John R. Facey  
Washington, DC 20546

NASA  
NASA Headquarters  
Attn: MOK/Mr. William E. Oliver, Jr.  
Washington, DC 20546

NASA  
NASA Headquarters  
Attn: LB/Mr. Vincent J. Sansevero  
Washington, DC 20546

NASA  
NASA Headquarters  
Attn: MD/Mr. Ronald J. Harris  
Washington, DC 20546

NASA  
NASA Headquarters  
Attn: M-3/Mr. Thomas A. Utsman  
Washington, DC 20546

NASA  
NASA Headquarters  
Attn: R/Dr. Leonard A. Harris  
Washington, DC 20546

U. S. Air Force  
ESMC  
Attn: SE/Mr. L. J. Ullian  
Patrick AFB, FL 32925

