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TRADE STUDY - LIQUID HYDROGEN TRANSPORTATION - KENNEDY SPACE CENTER

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TRADE STUDY

LIQUID HYDROGEN TRANSPORTATION

KENNEDY SPACE CENTER

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TRADE STUDY

LIQUID HYDROGEN TRANSPORTATION

KENNEDY SPACE CENTER

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KENNEDY SPACE CENTER, FLORIDA
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SUMMARY

Liquid hydrogen requirements for Kennedy Space Center to support Space Transportation System operations during the period 1982 through 1991 have been established at 500,000 gallons per launch, excluding losses relating to transportation. At existing contract prices, this represents approximately 60 percent of the total cost of propellants and pressurants for Shuttle launch operations. In turn, transportation represents 25 percent of the total delivered cost of liquid hydrogen. Should the planned rate of 40 launches per year be achieved, the cost of transportation could exceed $50,000,000 by 1991.

Marshall Space Flight Center is responsible for procurement and logistics of liquid hydrogen for all Government users and has awarded a long-term supply contract to Air Products and Chemicals, Inc. to support U.S. East Coast requirements. The basic contract was for 12-1/2 years and included construction of a new, dedicated, 30-ton-per-day plant in New Orleans, Louisiana. Transportation provisions in the contract include a specified rate using vendor-owned standard 13,000-gallon mobile tankers through mid-1982. This study was initiated in cooperation with Marshall Space Flight Center and Air Products and Chemicals, Inc. to examine the transporting of liquid hydrogen from the vendor facilities in New Orleans to Kennedy Space Center using alternative transportation means to determine the optimum mode in terms of cost and operational effectiveness.

This study examines and compares sixteen selected transportation options using various combinations of barge, semitrailer tankers, and railcars to

meet the projected liquid hydrogen requirements during the Shuttle operational time frame. Each transportation option is examined as a complete operational concept and is analyzed in terms of operating, maintenance, offloading, and transfer costs and in terms of the following operational characteristics:

0 Adaptability to incremental investment for equipment based on Shuttle launch rates actually achieved.

0 Dependability in delivering liquid hydrogen requirements and susceptibility to serious or catastrophic accident.

0 Major additional facilities and construction required and time factors affecting such requirements.

0 Compatibility with existing liquid hydrogen onloading and off-loading facilities at the vendor plant and Kennedy Space Center facilities.

0 Intransit hazard posed to population centers between the point of origin and final destination.

0 Sensitivity to labor disputes, fuel shortages, or significant increases in personnel and equipment costs.

0 Sensitivity of each method of transportation to programmed rates of 40 launches per year and at reduced launch rates.

Based upon detailed comparison of cost and operational effectiveness of the sixteen liquid hydrogen transportation options addressed in this study and evaluation of the data pertaining to each option it is concluded that:

0 The most cost effective methods of transporting liquid hydrogen

from Air Products and Chemicals, Inc. in New Orleans to Kennedy Space Center include those options which maximize the use of existing NASA transportation resources (mobile tankers and railcars) and which supplement this capability with maximum capacity mobile tankers, procured on an incremental basis, as a function of STS program materialization.

0 Liquid hydrogen delivery by vendor-owned mobile tanker f.o.b. destination in accordance with the existing NAS8-31034 contract would not be cost effective if continued at the current transportation rate on a projected straight line cost basis.

0 Liquid hydrogen delivery by barge does not appear to be a cost effective or attractive method of transportation due primarily to high initial investment cost for facilities and equipment.

0 Liquid hydrogen delivery using additional NASA-procured 13,000-gallon mobile tankers is not a cost effective method of transportation due to the comparatively low volume and higher operating cost per pound of product delivered in comparison to other options; however, utilization of maximum capacity mobile tankers has significant cost advantages.

0 Liquid hydrogen delivery by railcar could be a cost effective method of transportation in the event other alternatives should prove not feasible for technological or other reasons.

Based upon program requirements in effect at the time of this study and the conclusions derived, it is recommended that a baseline support plan which includes maximum utilization of existing NASA liquid hydrogen mobile tankers and railcar transportation assets be implemented as the primary transportation method in support of Shuttle flight operations at Kennedy Space Center.

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1.0 INTRODUCTION

Marshall Space Flight Center (MSFC), Huntsville, Alabama, under contract NAS8-31034 awarded July 1, 1975, engaged Air Products and Chemicals, Inc. (APCI), New Orleans, Louisiana, to provide liquid hydrogen (LH_2) requirements for all East Coast Government users. LH_2 requirements to support Kennedy Space Center (KSC) Space Transportation System (STS) operations equate to approximately 60 percent of the total cost of propellants for KSC STS operations. Transportation of LH_2 represents a significant portion of that cost and could exceed $50,000,000 by 1991. The existing contract provides a transportation rate schedule only through mid-1982 and addresses delivery by 13,000-gallon (gal) mobile tankers under free-on-board (f.o.b.) destination or origin options. During Source Evaluation Board deliberations, it was recognized that the long-range transportation methods of delivery to KSC would require further detailed study to determine the most cost-effective method. For this reason, the following statement was placed in the transportation appendix to the contract: "The contractor is encouraged to provide alternate methods which he determines more cost effective."

KSC, in cooperation with MSFC and APCI, initiated this LH_2 transportation trade study to analyze and compare various transportation modes and combinations of modes and to permit assessment of transportation problems, costs, and intangible considerations. Some transportation options considered in the study will impact contract NAS8-31034 and will require approval of the MSFC Contracting Officer. Environmental impact assessments for various transportation modes were not included in this study.

2.0 SCOPE

This study examines and compares sixteen possible transportation options using various combinations of barge, semitrailer tankers (mobile tankers), and railcars to meet projected LH_2 requirements during the STS operational time frame, 1982 through 1991. Each option is examined as a complete operational concept and is analyzed in terms of operating, maintenance, offloading, and transfer costs. A comparison of the cost-effectiveness of each option is then presented in tabular and graphical form to facilitate evaluation of each method of transportation. A brief description of each option is presented below. Details of each option are presented in Appendices 1 through 16.

2.0 OPTION 1 (BARGE)

One YFNB* barge with 815,000-gal gross capacity transports LH_2 from APCI directly to KSC offloading terminals and storage spheres at Complex 39 (C-39), Pads A and B on a 12-day round trip schedule (Appendix 1).

* Yard freight nonpropelled

2.2 OPTION 2 (BARGE/RAILCAR COMBINATION)

One Government-owned barge, as in Option 1, delivers LH_2 directly to the offloading terminal and storage sphere at C-39, Pad A. LH_2 is transferred from the barge to 34,000-gal railcars for transport and offloading into the storage sphere at Pad B (Appendix 2).

2.3 OPTION 3 (BARGE/PIPELINE COMBINATION)

One Government-owned barge, as in Option 1, delivers LH_2 directly to the offloading terminal and storage sphere at C-39, Pad A. LH_2 is transferred by cross-country, vacuum-jacketed (VJ) pipeline to the storage sphere at Pad B (Appendix 3).

2.4 OPTION 4 (BARGE/13,000-GAL MOBILE TANKER COMBINATION)

One Government-owned barge, as in Option 1, delivers LH_2 directly to the offloading terminal and storage sphere at C-39, Pad A. LH_2 is transferred to 13,000-gal mobile tankers for transport and offloading into the storage sphere at Pad B (Appendix 4).

2.5 OPTION 5 (BARGE/INVENTORY TANK COMBINATION)

One Government-owned barge, as in Option 1, delivers LH_2 directly to the offloading terminal and storage sphere at C-39, Pad A. LH_2 is transferred to a 530,000-gal inventory tank near Pad A for subsequent transfer to 13,000-gal tankers for delivery and offload into the storage sphere at Pad B (Appendix 5).

2.6 OPTION 6 (13,000-GAL MOBILE TANKER/COMMON CARRIER)

Twenty Government-owned 13,000-gal LH_2 mobile tankers, transported by certified common carrier, deliver LH_2 from APCI directly to storage spheres at C-39, Pads A and B on a 56-hour round trip schedule (Appendix 6).

2.7 OPTION 7 (13,000-GAL MOBILE TANKER/GOCO* TRACTORS)

Twenty Government-owned 13,000-gal LH_2 mobile tankers, transported by GOCO tractors, deliver LH_2 from APCI directly to storage spheres at C-39, Pads A and B on a 56-hour round trip schedule (Appendix 7).

2.8 OPTION 8 (19,700-GAL MOBILE TANKER/COMMON CARRIER)

Twelve Government-owned 19,700-gal LH_2 mobile tankers, transported by certified common carrier, deliver LH2 from APCI directly to storage spheres at C-39, Pads A and B on a 56-hour round trip schedule (Appendix 8).

2.9 OPTION 9 (19,700-GAL MOBILE TANKER/GOCO TRACTORS)

Twelve Government-owned 19,700-gal LH_2 mobile tankers, transported by GOCO tractors, deliver LH_2 from APCI directly to storage spheres at C-39, Pads A and B on a 56-hour round trip schedule (Appendix 9).

2.10 OPTION 10 (APCI 13,000-GAL MOBILE TANKER - F.O.B. KSC PADS)

APCI-owned and -operated 13,000-gal LH_2 mobile tankers and tractors deliver LH_2 from APCI directly to storage spheres at C-39, Pads A and B f.o.b. KSC (Appendix 10).

2.11 OPTION 11 (APCI 13,000-GAL MOBILE TANKER - F.O.B. KSC INVENTORY TANK)

APCI-owned and -operated 13,000-gal LH_2 mobile tankers and tractors deliver LH_2 from APCI directly to a 125,000-gal inventory tank f.o.b. KSC. Subsequently, LH_2 is transferred into KSC mobile tankers for transport directly to storage spheres at C-39, Pads A and B (Appendix 11).

* Government-owned, contractor-operated

2.12 OPTION 12 (34,000-GAL RAILCARS)

Eighteen Government-owned 34,000-gal LH_2 railcars deliver LH_2 from APCI directly to storage spheres at C-39, Pads A and B on an expedited 9-day round trip schedule (Appendix 12).

2.13 OPTION 13 (SPECIAL TRAIN - EIGHTEEN 34,000-GAL RAILCARS)

A Government-owned special train (including engine, caboose, idler cars, and eighteen 34,000-gal railcars) delivers LH_2 from APCI directly to storage spheres at C-39, Pads A and B. Operators for the special train are provided by the railroad (Appendix 13).

2.14 OPTION 14 (SPECIAL TRAIN - THIRTY-SIX 34,000-GAL RAILCARS)

A Government-owned special train (including engine, caboose, idler cars, and thirty-six 34,000-gal railcars) delivers LH_2 from APCI directly to storage spheres at C-39, Pads A and B. Operators for the special train are provided by the railroad (Appendix 14).

2.15 OPTION 15 (COMBINED ASSETS - RAILCARS)

Seven, existing, KSC-owned 13,000-gal mobile tankers combined with four, existing, NASA -owned 34,000-gal railcars and six additional 34,000-gal railcars deliver LH_2 from APCI directly to storage spheres at C-39, Pads A and B. Mobile tankers are transported by common carrier on a 56-hour round trip schedule. Railcars are moved by scheduled carrier on a 9-day turnaround schedule (Appendix 15).

2.16 OPTION 16 (COMBINED ASSETS - MOBILE TANKERS)

Seven, existing, KSC-owned 13,000-gal mobile tankers and four, existing, NASA-owned 34,000-gal railcars combined with four additional

19,700-gal Government-owned mobile tankers deliver LH_2 from APCI directly to storage spheres at C-39, Pads A and B. Tankers are transported by common carrier on a 56-hour round trip schedule. Railcars are moved by scheduled carrier on a 9-day turnaround schedule (Appendix 16).

2.17 OTHER OPTIONS

Other LH_2 transportation methods were examined, but were not considered viable options due to excessive cost or technical problems. Specific options considered and reasons for rejection follow.

2.17.1 Air Delivery. Air delivery using both fixed and transportable cryogenic tanks carried in C-5A Air Force cargo aircraft or in cargo version Boeing 747 aircraft was considered. Both air delivery options were rejected because of excessively high aircraft operating costs, traffic restrictions on transportable tanks, and unacceptably high transfer losses associated with onloading and offloading fixed aircraft-mounted cryogenic tanks.

2.17.2 NSTL Barges. Sea delivery using the existing Government-owned National Space Technology Laboratory (NSTL) barges was considered; however, these barges are neither constructed for, nor adaptable to, open sea transportation by seagoing tug. Intracoastal waterway travel would not be cost effective due to speed restrictions and round trip transit time required..

3.0 ASSUMPTIONS

In preparing this study, certain assumptions relative to LH_2 launch requirements, methods of delivery, cost factors, and transportation schedules were essential. Major assumptions used in this study to determine cost-effectiveness are summarized in the following paragraphs.

3.1 LH_2 REQUIREMENTS

KSC LH_2 requirements for the period mid-1982 through 1991 are assumed to be 500,000 gal per launch. Specific operational requirements upon which this assumption is based are indicated below.

OPERATIONAL REQUIREMENT	LH_2 VOLUME (GAL)
External Tank (ET) Loading	381,800
ET Transfer Losses	94,100
ET Boiloff (Prelaunch)	14,900
Fuel Cell (FC) Loading	593
FC Transfer Losses	1,407
OPF* GH_2 Requirements	10
FC GH_2 Requirements	53
Pad Boiloff (A and B)	3,970
Total	496,033

3.2 LAUNCH RATE

This study is based on an assumed rate of 40 STS launches per year beginning in 1984 as depicted in the 572 flight traffic model in PCIN** 01268 to JSC*** 07700 Level II Program Definition and Requirements, Volume III.

* Orbiter Processing Facility
** Program Change Identification Number
*** Johnson Space Center

YEAR	LAUNCHES
1982 (last half)	13
1983	36
1984 through 1991	40/Year

3.3 TANKER MILEAGE RATES

Common carrier rates for a new Section 22 (Interstate Commerce Act) Agreement are assumed to be the same as tanker mileage rates from APCI to KSC under the existing LH_2 contract (NAS8-31034) rates by mid-1982. Common carrier rates have been equivalent or higher than rates for transporting NASA-owned 13,000-gal LH_2 tankers since Matlock, Inc. cancelled its contract with NASA under Section 22 of the Interstate Commerce Act. Contract mileage rates for LH_2 tankers f.o.b. KSC for 1982 follow.

DELIVERY OPTION	RATE
APCI Tractor and Mobile Tanker	\$1.67/Mile
APCI Tractor with KSC-owned Mobile Tanker	\$1.12/Mile

3.4 SUPPLY

The maximum volume of LH_2 which can be removed from APCI storage facilities for loading onto barge, rail, or other transportation means at one time is assumed to be 500,000 pounds (844,700 gal). LH_2 regeneration capacity for APCI is assumed to be 30 tons (100,000 gal) per day.

3.5 LH_2 SPHERES (PADS A AND B)

The LH_2 spheres at Pads A and B are assumed to be filled to 850,000-gal capacity prior to beginning the STS launch cycle. The delivery window for resupply of LH_2 spheres is assumed to be days 1 through 7 of the 9-day launch cycle for all options.

3.6 COST ESCALATION

All costs associated with LH_2 transportation are assumed to escalate at a uniform rate of 7 percent per year throughout the time frame of this study. Labor costs are based on a 1976 contract rate of $13.00 per hour.

3.7 CONVEYANCE CAPACITIES

Loading of LH_2 mobile tankers by APCI is assumed to be based on reduction of gross volume by 6 percent for ullage, plus a 6-percent water density safety factor as follows.

TYPE CONVEYANCE	GROSS CAPACITY (GAL)	LH_2 LOAD (GAL) APCI
Mobile Tanker	13,270	11,700
Mobile Tanker	19,700	17,600
Railcar	36,000	31,700
Barge	815,000	725,000

3.8 BACKUP SUPPORT

The 49 APCI owned and operated LH_2 mobile tankers are assumed to be capable of providing contingency backup support for KSC after mid-1982; however, such support would require revision of the MSFC-APCI contract to provide for this contingency.

3.9 DECISION TIMETABLE

Investment costs in this study assume that selection of a specific LH_2 transportation option and determination of contract requirements will be made prior to finalization of the FY-78 budget. This is essential because in the normal KSC budgeting cycle, allocation of funds must precede contracting actions by at least 1 year and must precede facilities construction operations by at least 2 years.

3.10 ENVIRONMENTAL CONSIDERATIONS

Environmental considerations are assumed to have no significant influence on the rail and mobile tanker transportation options addressed in this study; however, possible special environmental impact on barge transportation is discussed in paragraph 5.4.

3.11 REDUCED LAUNCH FREQUENCY

The cost-effectiveness of some LH_2 transportation options are significantly affected by STS launch frequency. To assess STS reduced launch rate sensitivity, an assumed rate of 20 launches per year was used in this study. Derivation of estimated costs for each option at the reduced launch frequency is discussed in Appendices 1 through 16.

3.12 APCI-KSC TRAVEL TIME

The assumed travel time, including loading time at APCI facilities and offloading time at KSC, for each LH_2 transportation mode addressed in this study follows. Times are based on 24-hour day delivery schedules.

TRANSPORTATION	ROUND TRIP
Mobile Tankers	56.0 Hours
Railcars	9.0 Days
Special Train	4.5 Days (18 Railcars)
Special Train	6.5 Days (36 Railcars)
Barge	12.0 Days

3.13 OFFLOADING SUPPORT PERSONNEL

No special Security or Quality Assurance personnel are assumed to be required for LH_2 offloading operations as was done under the Apollo program. The Quality Assurance function will be performed by the Vehicle Operations (VO) Lead Technician and security will be provided by Safety and other VO personnel required at the off-loading site.

3.14 SHUTTLE OPERATIONAL TURNAROUND ANALYSIS REPORT (STAR)

Current STAR timetables indicate LH_2 sphere refill within a 160-hour turnaround by waves of four LH_2 13,000-gal mobile tankers immediately following each STS launch. As the large volume barge makes only 30 LH_2 deliveries and the special 36-railcar train makes only 20 LH_2 deliveries for each 40 STS launches per year, it is assumed that adoption of the barge or special train options would require revision of the STAR timetable. However, these options should not delay scheduled STS launches and, with the exception of hypergolic operations, should not affect normal pad activities. No constraints on Pad access for LH_2 delivery are indicated in STAR timetables.

4.0 DISCUSSION

4.1 GENERAL

In assessing the effectiveness of each LH_2 transportation option, overall cost is the governing consideration. The cost sensitivity of LH_2 transportation is clearly illustrated by the fact that for standard 13,000-gal mobile tankers, a saving of $0.01 per mile in 1982 will equate to $500,000 by 1991. As overall cost depicted in this study includes investment, operating, maintenance, offloading, and transfer/efficiency losses, a brief description of the methods by which each of these costs were derived follows.

4.1.1 <u>Investment Cost.</u> Investment cost included in this study consists of equipment procurement and facilities construction requirements for each transportation option. To the extent possible, investment costs were derived in accordance with NASA Management Instruction 7330.2A. All facilities and construction costs were derived by applying the following formula:

Budget Estimate = E (1+C)(1+F)(1+G)

E = Engineering Estimate (mid-1977)

C = Contingency Factor of 15 Percent

F = The cost-use factor based on 7 percent per year compounded annually from mid-1977 to the midpoint of construction.*

G = Outside agency administration cost factor of 10 percent for contract supervision and inspection.

* Mid-1981 was used as the average construction midpoint.

Additive to the foregoing costs is the NASA design cost of 6 percent to allow for preparation of specifications, drawings, environmental assessments, and bid packages.

Equipment costs addressed in the investment section of each transportation option were derived by considering informal estimates provided by industry as vendor estimates. Budget estimates were then derived from vendor estimates by applying a 7-percent-per-year escalation factor plus a 10-percent cost adjustment factor.

4.1.2 Operating Cost. Operating cost in this study includes four categories of special charges other than operator personnel costs. Barge operating cost includes the lease or charter rates for seagoing or inland waterway tugs. Railcar costs include freight charges; switching charges; and, for special trains, crew and fuel costs. Mobile tanker costs using GSA* tractors include mileage charges plus monthly lease charges for procuring replacement equipment while mobile tanker costs using common carrier delivery include only fixed rate mileage charges based upon established contract agreements.

4.1.3 Maintenance Cost. Maintenance cost included in this study includes preventive and corrective maintenance, cleaning and lubricating materials, corrosion control, cryogenic refurbishment and any other specialized repair required to maintain LH_2 transportation equipment in satisfactory operating condition. To the extent possible, experience factors with existing equipment were used to estimate

* Government Services Administration

maintenance cost. For example, actual APCI maintenance cost data for LH_2 mobile tankers are available and limited maintenance data are available from Linde for 34,000-gal railcars with superinsulation. Maintenance data for YFNB barge operations, however, are based solely on industrial source (shipyard) estimates for similar type equipment and NSTL experience with the smaller LH_2 barges.

4.1.4 Offloading Cost. Offloading cost included in this study is based on personnel requirements to perform Fire, Safety, Security, and specialized operator functions associated with transferring LH_2 from a specific type tanker to an inventory or pad storage sphere at KSC. The guidance used in determining offloading requirements was LS-ENG-2 memorandum dated December 19, 1975, Subject: Shuttle Operating Plans and Interfaces. Specialized offloading functions other than Fire, Security, and Safety include positioning of LH_2 tankers, connecting hoses to offloading manifolds, purging offloading lines and hoses, pressurizing the offloading tanker, transfer of LH_2 to the storage/holding sphere, venting, purging the manifold lines, and disconnecting the transfer hoses. No Security personnel are provided for offloading as this function will be performed by onsite VO and Safety personnel. The Quality Assurance function will be performed by the lead VO technician present for offloading operations.

4.1 5 Transfer/Efficiency Cost. The transfer/efficiency cost included in this study consists of pressurization loss incurred during LH_2 tanker offloading, chilldown loss encountered in reducing storage tank temperatures below -423° Fahrenheit, heat leak transfer, line loss (residual), and LH_2 boiloff (heat gain) loss incurred enroute between APCI and KSC. Transfer/efficiency losses are based on an average cost of $1.28 per pound during the period 1982 through 1991 at the launch rate detailed in paragraph 3.2. A tabular summary of estimated transfer/efficiency losses for all options in this study is presented in Appendix 17.

4.1.6 Comparison of Options. A cost comparison of estimated investment, operating, maintenance, offloading, and transfer/ iency costs for each of the 16 options addressed in this study resented in Tables 1 and 2. Table 1 is based on 40 launches per year. A graphical comparison of the relative cost-effectiveness of each principal mode of transportation is presented in Tables 3 and 4 and a decision time table indicating dates by which transportation options must be selected and implemented is presented in Table 5.

A summary of the relative advantages and disadvantages of each of the transportation methods and options used in this study is presented in the following paragraphs. In each case, the most cost effective option of each method (best barge option, best railcar option, best mobile tanker option, etc.) is determined and the relative advantages and disadvantages of each mode of transportation are then compared.

4.2 BARGE OPTIONS

Option 1 (Barge to Pads A and B) is the most cost effective barge option at launch frequencies of 25 per year or greater. Although initial investment cost for Option 1 is greater, the

LH_2 TRANSPORTATION OPTIONS	GOVERNMENT COSTS (X $1,000)					
	INVESTMENT	OPERATIONS	MAINTENANCE	OFFLOADING	TRANSFER EFFICIENCY	TOTAL
1. BARGE TO PADS A AND B	26,600	22,800	2,600	400	10,300	62,700
2. BARGE WITH RAILCAR	19,000	22,900	2,800	1,8[illegible]	1[illegible]	64,000
3. BARGE WITH PIPELINE	33,000	22,900	2,900	400	14,500	73,700
4. BARGE WITH TANKERS	19,400	23,400	3,300	2,800	17,600	66,500
5. BARGE WITH INVENTORY TANK	24,800	23,300	3,600	5,000	22,300	79,000
6. 13,000-GAL TANKER - COMMON CARRIER	5,300	39,500	2,900	3,300	14,000	65,000
7. 13,000-GAL TANKER - GOCO TRACTOR	6,500	36,800	2,900	3,300	14,000	63,500
8. 19,700-GAL TANKER - COMMON CARRIER	9,400	26,600	2,100	3,500	13,800	55,400
9. 19,700-GAL TANKER - GOCO TRACTOR	10,100	24,800	2,100	3,500	13,800	54,300
10. 13,000-GAL TANKER - F.O.B. PADS	-	57,900	-	2,300	14,000	76,300
11. 13,000-GAL TANKER - F.O.B. INVENTORY TANK	3,900	60,400	1,000	9,400	22,300	97,500
12. 34,000-GAL RAILCARS	13,500	29,200	1,100	1,600	13,000	58,400
13. SPECIAL TRAIN (18-CAR)	14,400	33,200	1,200	1,600	11,700	62,100
14. SPECIAL TRAIN (36-CAR)	22,900	24,400	2,200	3,200	12,200	64,900
15. COMBINED ASSETS-RAILCARS	7,800	32,700	2,100	1,500	13,300	57,400
16. COMBINED ASSETS-TANKERS	3,700	32,100	2,400	3,000	13,600	54,800

TABLE 1

LH_2 TRANSPORTATION COSTS

(40 LAUNCHES PER YEAR)

LH_2 TRANSPORTATION OPTIONS	GOVERNMENT COSTS (X \$1,000) INVESTMENT	OPERATIONS	MAINTENANCE	OFFLOADING	TRANSFER EFFICIENCY	TOTAL
1. BARGE TO PADS A AND B	26,600	11,400	2,600	200	7,700	48,500
2. BARGE WITH RAILCAR	19,000	11,400	2,800	900	11,200	45,300
3. BARGE WITH PIPELINE	33,000	11,400	2,900	200	9,600	57,100
4. BARGE WITH TANKERS	19,400	11,600	3,300	1,400	15,900	51,600
5. BARGE WITH INVENTORY TANK	24,900	11,600	3,600	2,500	15,900	58,500
6. 13,000-GAL TANKER - COMMON CARRIER	300	19,800	1,100	1,600	7,000	29,800
7. 13,000-GAL TANKER - GOCO TRACTOR	800	18,400	1,100	1,600	7,000	28,900
8. 19,700-GAL TANKER - COMMON CARRIER	5,000	13,300	1,000	1,800	6,900	28,000
9. 19,700-GAL TANKER - GOCO TRACTOR	4,700	12,400	1,000	1,800	6,900	26,800
10. 13,000-GAL TANKER - F.O.B. PADS	--	28,900	--	1,200	7,000	37,100
11. 13,000-GAL TANKER - F.O.B. INVENTORY TANK	3,900	30,400	1,000	4,700	11,700	51,700
12. 34,000-GAL RAILCARS	4,100	14,600	600	800	6,600	26,700
13. SPECIAL TRAIN (18-CAR)	14,400	16,600	1,200	800	5,800	38,800
14. SPECIAL TRAIN (36-CAR)	22,900	12,200	2,200	800	6,600	44,700
15. COMBINED ASSETS - RAILCARS	--	16,800	1,700	1,200	6,700	26,400
16. COMBINED ASSETS - TANKERS	3,700	16,000	1,900	1,500	6,700	29,900

TABLE [illegible]

LH_2 TRA[illegible]S

(20 LAU[illegible] YEAR)

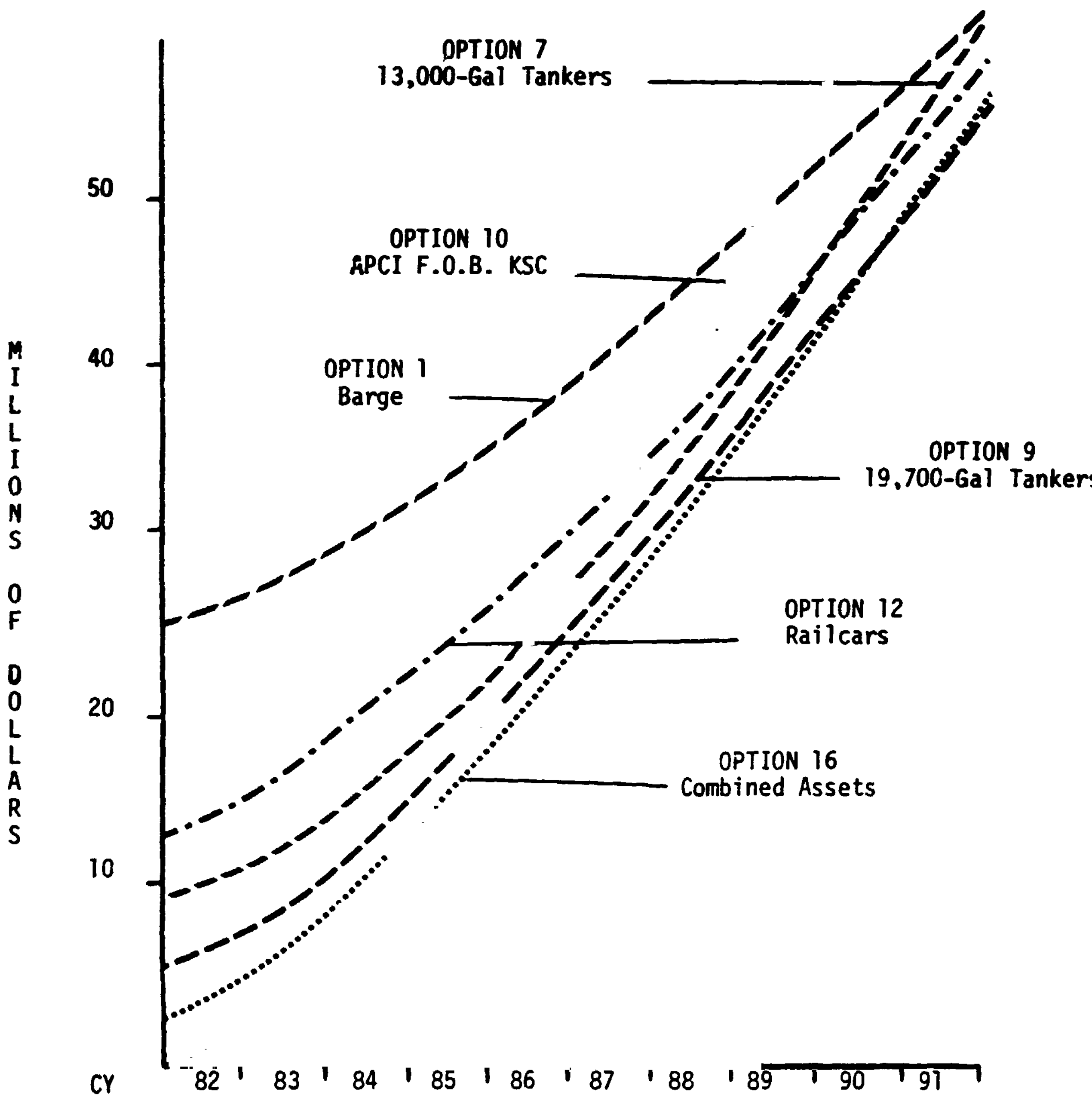

TABLE 3

COST COMPARISON

40 LAUNCHES PER YEAR

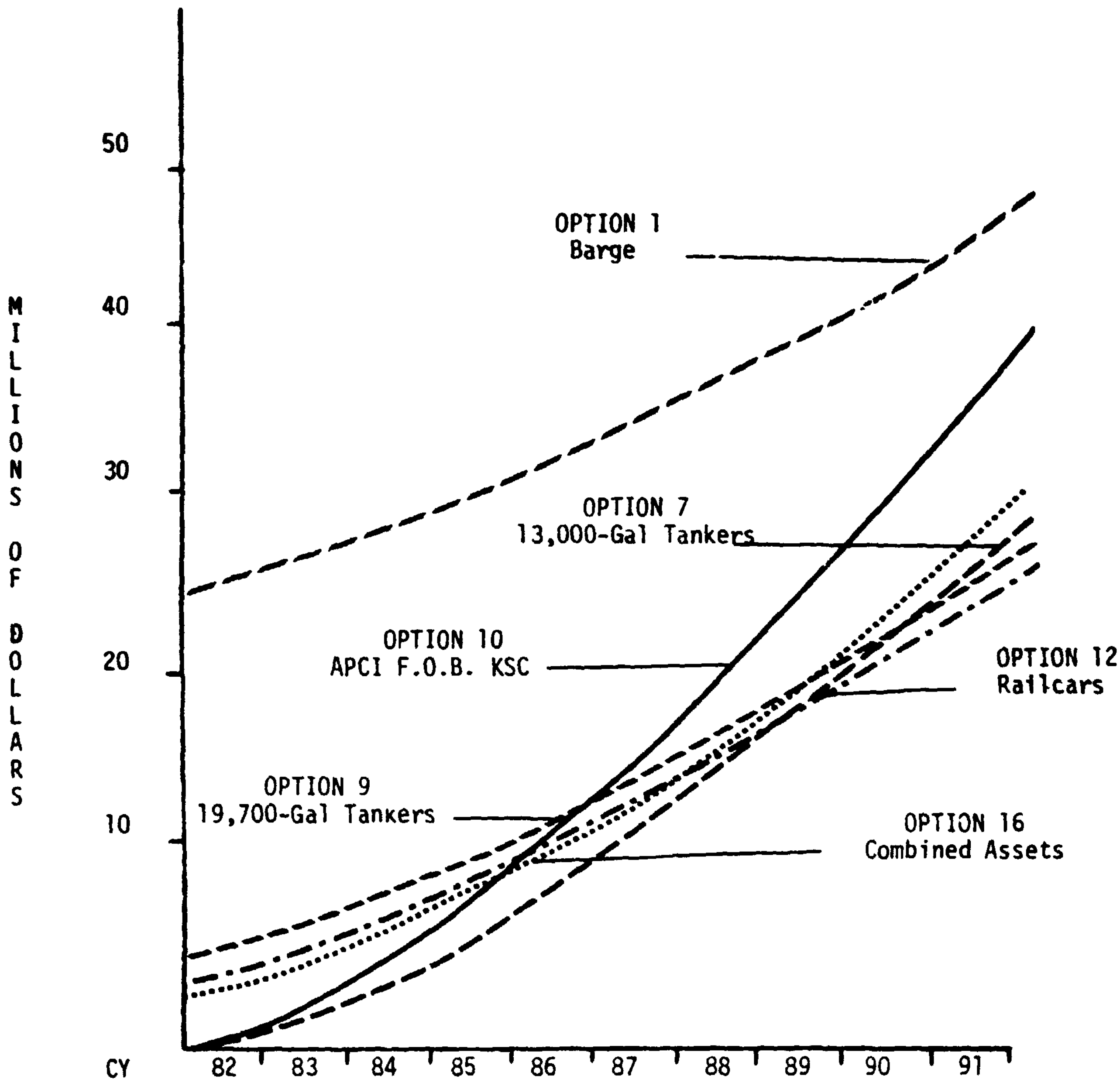

TABLE 4

COST COMPARISON

20 LAUNCHES PER YEAR

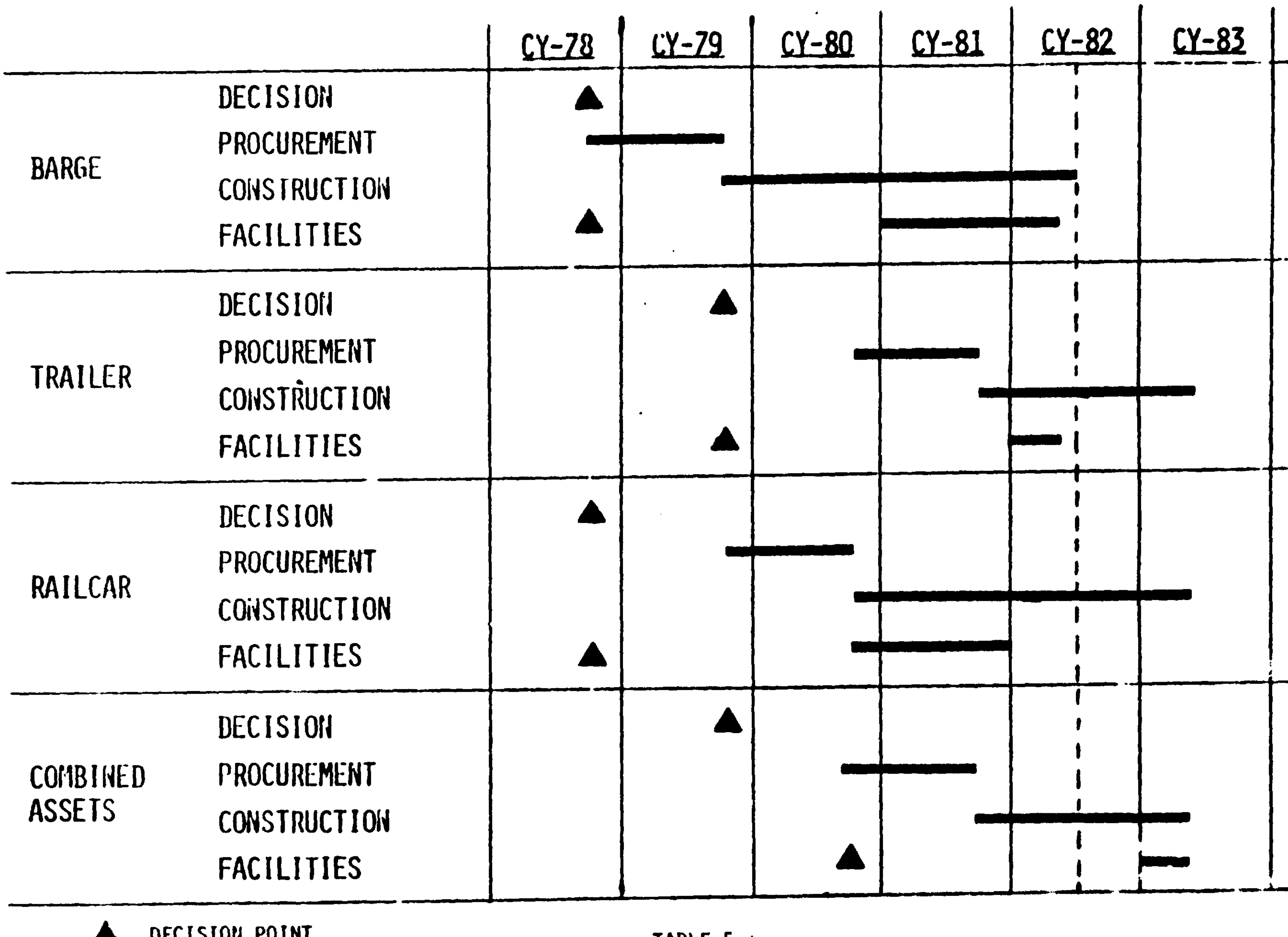

TABLE 5
DECISION/IMPLEMENTATION SCHEDULE

increase in transfer/efficiency losses which result from double offloading of LH_2 into railcars, mobile tankers, inventory tanks, and long pipelines, makes other barge options (2 through 5) marginally effective. However, none of the barge options are cost effective when compared with most other options due to high investment costs. For example, Option 1 is seventh most cost effective when compared with other options at 40 launches per year; and, for the first 260 STS launches (mid-1989) even APCI delivery f.o.b. destination is more cost effective than the best barge option. At launch frequencies less than 20 per year, initial investment costs become the dominant barge factor and Option 2 (Barge/Railcar Combination) becomes most cost effective of the barge options. A summary of advantages and disadvantages of the barge options follow.

4.2.1 Advantages. Barge transportation is most economical of all modes of transportation in terms of operating and offloading costs.

Barge transportation is compatible with existing APCI facilities and would require little additional construction investment in New Orleans.

The open sea route traversed by barge from New Orleans to KSC minimizes the LH_2 hazard to populated areas in the event of catastrophic accident.

Pad access time is minimized by barge delivery; and potential interference with hypergol, liquid oxygen (LO_2), or other sensitive STS operations is greatly reduced.

Personnel and administrative requirements (scheduling, dispatch, etc.) are minimal for both APCI and KSC operations.

4.2.2 Disadvantages. The large initial investment requirement precludes incremental investment at a rate consistent with reduced launch frequencies.

Extensive canal dredging and construction of barge offloading facilities must be accomplished at KSC to provide access to LH_2 storage dewars at Pads A and B.

Environmental Protection Agency (EPA) impact investigation and consent is required for dredging of canals prior to implementation of this option.

The barge option requires the longest construction lead time with earliest commitment of funds and least program experience prior to commitment of funds.

Barge transportation is most sensitive to accident with no backup available in the event of major damage or delay.

Barge transportation is most vulnerable to severe weather as 20-foot seas can adversely affect barge tow cable operations.

Slow turnaround (12 days) limits round trips to 30 per year maximum and precludes supporting STS operations at rates greater than 40 launches per year.

At lower launch frequencies (20 per year), excessive investment costs make barge operations noncompetitive with other methods of LH_2 transportation.

4.3 13,000-GAL MOBILE TANKER OPTIONS

LH_2 delivery using KSC-owned 13,000-gal mobile tankers transported by GSA Government-owned, contractor-operated trucks (Option 7) is the most cost effective ` the 13,000-gal mobile tanker options. However, this option is only eighth most cost effective when compared with other options at 40 STS launches per year. The comparatively small capacity of these mobile tankers and the large number of deliveries required to support each STS launch are key factors. At $1500 per round trip delivery for one 13,000-gal mobile tanker, the 48 mobile tanker loads required for each STS launch result in excessively high operating costs. For example, due to initial investment, LH_2 delivery by this option is more expensive than APCI delivery f.o.b. destination for the first 160 STS launches (end 1986). For decreased launch rates of 20 per year or less, the reduction in major investment cost for 13,000-gal mobile tankers makes this option second most cost effective when compared with barge, railcar, and other mobile tanker options. A summary of advantages and disadvantages of 13,000-gal LH_2 mobile tanker options follows.

4.3.1 Advantages. LH_2 transportation by 13,000-gal mobile tanker offers maximum possibility for incremental investment, and the number of mobile tankers required can be tailored to actual launch rates achieved.

Initial investment cost for sufficient 13,000-gal mobile LH_2 tankers to support STS operations are lower than for comparable barge or railcar equipment.

The 13,000-gal LH_2 mobile tanker is a standard, proven design and no additional investment costs for onloading facilities at APCI or offloading facilities at KSC are required.

LH_2 delivery by 13,000-gal mobile tanker is highly versatile and reliable, and the impact of a single catastrophic accident is minimized.

4.3.2 Disadvantages. The comparatively small volume of LH_2 transported by each mobile tanker results in a higher cost per pound-of-product-delivered than all other options.

Special Department of Transportation (DOT) permits and exemptions are presently required for interstate delivery of LH_2 by this method. Risk of catastrophic accident and intransit hazard to populated areas are significantly greater due to the number of round trips required (1,920 per year).

LH_2 resupply requires constant access (days 1 through 7 following launch) to the storage spheres at Pads A and B, which could impact hypergol, LO_2, or other STS operations.

Maintenance and offloading costs for the 13,000-gal mobile tankers are significantly higher than for other methods of transportation.

Maintenance and offloading costs for the 13,000-gal mobile tankers are significantly higher than for other methods of transportation.

This method is more vulnerable to increases in fuel costs than other transportation options (Appendix 18) and consumes 4.3 million more gallons of diesel fuel than a special train carrying the same volume of LH_2. It is also more vulnerable and sensitive to strikes and labor disruptions either by KSC or common carrier employees than other options.

4.4 19,700-GAL MOBILE TANKER OPTIONS

LH_2 delivery by KSC-owned 19,700-gal mobile tankers transported by GSA Government-owned, contractor-operated tractors is most cost effective of all transportation options. In addition, this method is second most cost effective in terms of overall cost at launch frequencies less than 40 per year. Due to initial investment costs, this option becomes more cost effective than APCI delivery f.o.b. destination only after 130 STS launches (end 1985). Although mobile tanker cost-effectiveness is directly proportional to tanker volume, 19,700 gal represents the maximum volume possible without building oversized tankers. Oversized tankers would require special permits, with possible restriction to daylight hour travel, and escort required in some states. As Florida and Mississippi indicate only 60-day permits would be issued for oversize tankers, increased volume was not considered feasible. A summary of advantages and disadvantages of 19,700-gal mobile tankers follows.

4.4.1 Advantages. LH_2 transportation by 19,700-gal mobile tanker offers maximum possibility for incremental investment as the number of tankers required can be tailored to actual launch rates.

Initial investment costs are moderate and are significantly lower than costs for comparable barge and railcar equipment.

LH_2 delivery by 19,700-gal mobile tanker is highly versatile and reliable and the impact of a single catastrophic accident is minimized.

The 19,700-gal mobile tankers would be compatible with KSC and APCI onloading and offloading facilities and no new construction would be required.

Operating costs for 19,700-gal mobile tankers are lower than any other method per pound-of-product-delivered at decreased launch frequencies of approximately 20 per year.

4.4.2 Disadvantages. The 19,700-gal mobile LH_2 tanker is a new concept and would require design time and DOT approval and exemptions prior to production and use by KSC. Rectangular design technology would probably be required.

Risk of catastrophic accident and transit hazard to populated areas are high due to the number of round trips required (1,280 per year).

LH_2 resupply requires constant access (days 1 through 7 following launch) to the storage spheres at Pads A and B, which could impact hypergol, LO_2, or other STS operations.

This method is highly vulnerable to increases in fuel cost and, during the period 1982 through 1991, consumes 3 million gal more diesel fuel than a special train transporting an equal volume of LH_2.

This method is highly vulnerable and sensitive to strikes and labor disruptions either by KSC or common carrier employees.

4.5 APCI DELIVERY F.O.B. DESTINATION

APCI delivery of LH_2, f.o.b. Pads A and B, using APCI-owned and APCI-operated 13,000-gal LH_2 mobile tankers is the least cost effective of all options. In particular, APCI delivery to a KSC inventory tank for further transfer to storage tanks at Pads A and B is prohibitively expensive due to almost doubled offloading and LH_2 transfer costs. A comparison of delivery costs between APCI delivery, f.o.b. Pads A and B, indicates that APCI's charge using 13,000-gal mobile tankers is approximately 20 percent greater than KSC's cost using identical methods of delivery. This probably represents the margin for APCI profit and amortization of the fleet cost for 26 mobile tankers. It should be noted that, by providing the seven KSC-owned 13,000-gal mobile tankers to APCI for deliveries to KSC, operating costs for this option could be reduced approximately $6 million by 1991 (see paragraph 3.0, Appendix 10). Advantages and disadvantages of APCI delivery f.o.b. destination (Option 10) follow.

4.5.1 Advantages. Initial investment and maintenance costs are entirely eliminated as all equipment associated with this method is APCI-owned and APCI-operated.

No major additional facilities or construction at either KSC or APCI are required to support this option.

The risk of catastrophic accident and hazards to populated areas enroute is the problem and responsibility of APCI.

LH_2 delivery by mobile tanker is highly versatile and reliable and the impact of a single catastrophic accident is minimized.

4.5.2 Disadvantages. The operating costs for this option are the highest and would total at least $15 million more than barge, railcar, or 19,700-gal mobile tanker operations for the period 1982 through 1991 if 40 launches per year are realized.

LH_2 resupply requires constant access (days 1 through 7 following launch) to the storage spheres at Pads A and B, which could impact hypergol, LO_2, or other STS operations. Any delays could result in major cost increases for demurrage.

This method is most vulnerable and sensitive to strikes and labor disruptions by contractor personnel at KSC as APCI drivers will not cross picket lines.

4.6 RAILCAR/SPECIAL TRAIN OPTIONS

Railcar delivery by scheduled carrier (Option 12) using 18 railcars on a 9-day schedule is most cost effective of the three railcar/

special train options. However, this option is only fifth most cost effective when compared with other options at a rate of 40 STS launches per year. Railcar cost-effectiveness is reduced by the high initial investment cost for railcars and because of major track modifications/extensions required at both KSC and APCI. Special train cost-effectiveness was further reduced by the high rate quoted by Florida East Coast (FEC) Railroad for the KSC special train options. The FEC rate resulted in excessively high round trip operating costs. As rail delivery efficiency is directly dependent upon the number of railcars in the train, the short (18 car or less) trains are not cost effective. For example, railcar delivery costs are less cost effective than APCI delivery f.o.b. KSC the first 210 STS launches (end 1987). A summary of advantages and disadvantages of railcar and special train LH_2 transportation follows.

4.6.1 Advantages. Railcar options permit incremental investment at rates which are consistent with and proportional to scheduled STS launch frequencies.

LH_2 railcars are of standard, proven design and no special permits or transportation exemptions are required for movement in interstate commerce.

LH_2 railcars have large capacities and offer reduced transportation cost per pound-of-product-delivered over most other methods when trains of 30 railcars or more are used.

Railcar LH_2 resupply can be accomplished in shorter time and is sufficiently flexible to support launch frequencies much greater than 40 per year.

Special trains would use approximately 4.3 million gal less diesel fuel than truck transportation options during the time frame 1982 through 1991.

4.6.2 Disadvantages. Investment costs for railcars and special train options are high, making special trains marginally cost effective at reduced launch rates.

Major additional investment for extension and modification of tracks and facilities at APCI in New Orleans is required to support railcar and special train operations.

Major additional investment for extension of tracks and modifications of offloading facilities at KSC are required to support railcar operations.

Railcar transportation poses a relatively high LH_2 hazard to populated areas in the event of catastrophic accident.

4.7 COMBINED ASSETS OPTIONS

LH_2 delivery using combinations of existing KSC-owned, 13,000-gal mobile tankers and NASA-owned, 34,000-gal railcars in combination with 19,700-gal mobile tankers or additional 34,000-gal railcars is second most cost effective of all LH_2 delivery methods. Option 16 is most cost effective at 40 STS launches per year or greater while Option 15 is the most cost-effective delivery method for 20 STS launches or less. The low initial investment for equipment and facilities plus the ability to procure equipment incrementally in accordance with actual STS launch rates achieved makes these options particularly attractive and effective. Overall cost-effectiveness is further emphasized by the fact that after only 80 launches (late 1984), total costs for Option 16 are less than APCI delivery f.o.b. destination. A summary of major advantages and disadvantages of the combined asset options follows.

4.7.1 Advantages. This method optimizes the use of existing equipment and offers maximum possibility for incremental investment as the number of tankers required can be tailored to actual launch rates.

Initial investment costs are significantly lower than for comparable barge, railcar, and even the all-19,700-gal mobile tanker option equipment.

LH_2 delivery by mobile tanker and railcar is highly versatile and reliable and the impact of a single catastrophic accident is minimized.

The mobile tankers and railcars are compatible with KSC and APCI onloading and offloading facilities and little new construction would be required.

Operating costs for the combined mobile tankers and railcars are lower than for any other method per pound-of-product-delivered at decreased launch frequencies of approximately 20 per year.

4.7.2 Disadvantages. The 19,700-gal mobile LH_2 tanker is a new concept and would require design time and DOT approval and exemptions prior to production and use by KSC. Rectangular design technology would probably be required.

Risk of catastrophic accident and transit hazard to populated areas is increased due to the number of round trips required.

5.0 PROBLEMS AND ISSUES

In assessing the cost-effectiveness of the transportation options addressed in this study, certain unresolved issues and potential problem areas which could significantly affect the selection of future LH_2 transportation methods became apparent. A summary of these issues and potential problem areas follows.

5.1 APCI F.O.B. DESTINATION RATES

The APCI rates for LH_2 transportation f.o.b. destination specified in contract NAS8-31034 include charges for amortization of the APCI mobile tanker and truck delivery fleet. In theory, amortization of the APCI fleet delivering LH_2 to East Coast Government users should be completed by mid-1982 when the existing negotiated contract rates expire. It would appear that, after the APCI mobile tanker fleet has been amortized, a lower transportation rate should be negotiated by MSFC for future delivery of LH_2.

5.2 NASA LH_2 RAILCARS

Four NASA-owned 34,000-gal LH_2 railcars are presently located at Lewis Research Center. As STS requirements for LH_2 increase at KSC, a need for these railcars to augment the existing KSC mobile tanker fleet will develop. In addition, should the railcar or special train options for LH_2 transportation be selected, availability of these four railcars could save $1.57 million in additional Government equipment investment costs. As these railcars are not being used by Lewis Research Center, the possibility of obtaining them for KSC use should be examined.

5.3 DOT EXEMPTIONS

DOT currently lacks a specification for the design and construction of LH_2 semitrailer tankers, however, DOT Specification MC-341 on this subject is pending approval/publication. The mechanism for DOT approval and control of LH_2 trailer design is the issuance of special permits which define original design and modification. The permits are renewed every other year upon review of certain records by DOT including modification, repairs, etc. The NASA Transportation Branch is responsible for the renewal of special permits for KSC. As any changes in design specifications could significantly affect existing 13,000-gal and proposed 19,700-gal KSC LH_2 mobile tankers, the DOT exemption policy should be closely monitored.

5.4 ENVIRONMENTAL IMPACT

Implementation of the barge option for LH_2 transportation will require extensive dredging to provide adequate canal access to Pads A and B. KSC Design Engineering (DE) and KSC Transportation Services indicate that study and approval of this concept by the U. S. Army Corps of Engineers and the EPA would be required prior to initiation of any action to widen or deepen the existing waterway or to dredge a new barge canal. An unfavorable environmental impact assessment could adversely affect the proposed barge option and will definitely increase lead time for facility construction.

5.5 RAILCAR SCHEDULES

Representatives of three railroads operating between KSC and the APCI facility in New Orleans have stated that a special 9-day round trip schedule for KSC LH_2 railcars is feasible. KSC Transportation Services states that if the switching of LH_2 railcars to waiting trains by scheduled rail carriers at their respective interface points can be expedited, the 9-day schedule can be achieved. Prior to implementing the railcar concept, penalty contract assurance of expedited railcar movement should be sought from each railroad concerned to preclude delayed handling and delivery.

5.6 BARGE SCHEDULING

Under ideal conditions, the barge option requires a 12-day round trip travel time. This schedule is not compatible with STAR and permits a maximum of 30-round-trip LH_2 deliveries per year to support 40 STS launches with a 5-day maintenance stand-down time and no weather delay. As the YFNB barge tow cable is affected by 20-foot seas and the average storm in the Gulf area is of 3-day duration, the possibility of weather delay is always present and could cause periodic delays of scheduled STS launch operations.

5.7 COMMON CARRIER RATES

The cost-effectiveness of f.o.b. origin delivery by common carrier will be determined by the results of future contract negotiations. The recent experience with Matlack, Inc. cancelling their agreement with NASA (which resulted in an immediate increase from $0.59 per mile to $1.06 per mile and subsequently to $1.12 per mile for tanker transportation) seems to emphasize the fragile nature of such agreements. The carrier may cancel such special agreements (negotiated under Section 22 of the Interstate Commerce Act) at any time with a 30-day notice.

5.8 OVERSIZE SEMITRAILER TANKERS

Maximum payload LH_2 semitrailer tankers of more than 20,000-gal capacity are potentially the most cost effective transportation option. Assurances were received that each of the states between KSC and APCI would permit 24-hour-per-day traffic for such oversized vehicles without special escort; however, firm assurance that oversize vehicle charges would not be levied for each trip were not received and two states indicated that no permits valid for more than 60 days without renewal would be issued. These considerations, combined with possible imposition of severe restrictions in the event of catastrophic accident influenced the decision not to use an oversize LH_2 tanker.

5.9 KSC RAILROAD TRACKS

KSC railroad tracks are in a poor state of repair and need maintenance. Serious problems with rails, ties, and switches exist due to deferred FEC maintenance, and KSC Transportation Services estimates that $3 million in repair costs are essential to bring the tracks to a fully serviceable condition. Before any railcar option for LH_2 transportation can be implemented, return of the KSC railroad tracks to a normal condition is essential.*

5.10 INITIAL INVESTMENT COST

The estimated investment cost for LH_2 barge, railcar, and semi-trailer tankers described in each of the options of this study are based on informal, telephonic market surveys of commercial firms which manufacture cryogenic tanker equipment. As none of the costs are actually based on firm bids or quotations in response to contract solicitation, some variations in price should occur in future LH_2 transportation procurement actions.

5.11 FUEL COST

In comparing operating costs, the fuel cost associated with each of the transportation options has been assumed to escalate at 7 percent per year. Fuel costs could escalate at a significantly greater rate as a result of National energy policy or special action by oil exporting nations. Should this escalation occur, the relative cost-effectiveness of all transportation options could be significantly affected. A summary of estimated fuel consumption and sensitivity of fuel cost to escalated rates appears in Appendix 18.

* Includes upgrading existing rail spurs at Pads A and B.

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5.12 KSC MOBILE TANKER FLEET

In the event barge, railcar, or all 19,700-gal mobile tanker options are selected for STS LH_2 transportation during the period 1982 through 1991, the existing KSC mobile tanker fleet of seven 13,000-gal and one 16,700-gal mobile tankers will be available for other possible use. Part of all of these mobile tankers can be leased to APCI as revenue-producing equipment or the tankers can be retained as an additional backup to the selected LH_2 transportation option.

5.13 YFNB-TYPE BARGE AVAILABILITY

The cost and development time for all barge options addressed in this study are based on availability of a suitable YFNB-type barge from the U. S. Navy. If a suitable barge is not available, the investment costs and equipment development schedules presented in Options 1 through 5 could increase significantly.

5.14 EQUIPMENT PROCUREMENT RESPONSIBILITY

In conjunction with the decision to proceed with a specific LH_2 transportation option, a determination must be made whether MSFC, KSC, or APCI would be responsible for acquiring the required conveyance(s). In additon, specific responsibilities associated with each transportation mode must be identified and assigned prior to implementing the transportation option.

5.15 BARGE DEVELOPMENT SCHEDULE

If the normal NASA-wide Research and Development (R&D) budgeting process is followed and the APCI time schedule for barge development can not be reduced below 3 years, the proposed LH_2 barge would probably not be operational prior to calendar year 1983. To achieve an operational status for the barge option by mid-1982, special funding to reduce lead time or an accelerated construction schedule is required prior to the fiscal year 1980 budget call.

6.0 CONCLUSIONS

Based upon detailed comparison of the sixteen LH_2 transportation options addressed in this study and evaluation of the data presented in each option it is concluded that:

- The most cost effective methods of transporting LH_2 from APCI to KSC include those options which maximize the use of existing NASA transportation resources (mobile tankers and railcars) and which supplement this capability with maximum capacity mobile tankers, procured on an incremental basis, as a function of STS program materialization.

- LH_2 delivery by APCI mobile tanker f.o.b. KSC in accordance with the existing NAS8-31034 contract would not be cost effective if continued at the current transportation rate on a projected straight line cost basis. However, the use of APCI mobile tankers for contingency backup support of KSC LH_2 transportation options implemented during the period 1982-1991 should be considered in future contract negotiations.

- O LH_2 delivery by barge does not appear to be either a cost effective or attractive method of transportation due to high initial investment cost for facilities and equipment, the requirement to commit extensive funds prior to determination of actual STS launch rates, limitations on round trip launch support capability, time constraints on construction and implementation, higher risk and possible environmental impact.

- O LH_2 delivery using additional NASA-procured 13,000-gal mobile tankers is not a cost effective method of transportation due to the comparatively low volume and higher operating cost per pound of product delivered in comparison to other options. Utilization of maximum capacity mobile tankers has significant cost advantages and should be pursued as an incremental additive to the existing KSC LH_2 transportation support baseline.

- O LH_2 delivery by railcar could be a cost effective method of transportation in the event other alternatives should prove not feasible for technological or other reasons. KSC procurement and use of the four NASA owned LH_2 railcars presently located at Lewis Research Center to develop additional operational baseline experience should be a priority consideration.

7.0 RECOMMENDATIONS

In accordance with the options addressed in this study and the conclusions presented, it is recommended that:

- O A baseline support plan which includes the total existing NASA LH_2 transportation capability be implemented as the LH_2 transportation method in support of KSC STS operations.

- O Action to coordinate this study with MSFC and APCI be initiated as soon as practical to facilitate planning, budgeting, and future contract negotiations for LH_2 transportation.

- O Coordination with Lewis Research Center be established for transfer of the four LH_2 railcars to support LH_2 delivery to KSC and developing an experience base utilizing railcars.

- O Coordination continue with industry for engineering design and valuation of maximum capacity LH_2 mobile tankers.

APPENDIX 1

APPENDIX 1

OPTION 1 - BARGE TO PADS A AND B

1.0 CONCEPT OF OPERATION

Option 1 is based on LH_2 delivery by Government-owned barge directly from the APCI facility in New Orleans to Pads A and B. Under this concept, two cylindrical LH_2 dewars, each with a 32-foot outer diameter and 110 feet in length, would be mounted on a YFNB hull similar to the type used for delivering Apollo hardware to KSC (Figure 1-1). The concept of using two tanks rather than a single long tank is more practical from a structural design standpoint and provides a measure of redundancy. The proposed tanks would have an aluminum inner tank and carbon steel outer tank with a perlite-filled, evacuated annulus. Overall barge size would be approximately 48 feet wide by 265 feet long with an adjustable 12 feet maximum and 3 feet minimum draft. Estimated boiloff would be 0.15 percent per day of full volume with a 50-psig operating pressure.

The barge would be sized to provide inventory storage over and above the estimated [illegible],000-gal LH_2 launch cycle requirement as the proposed barge is capable of a maximum of 30 deliveries from APCI to KSC per year. To support 40 launches, 20,000,000 gal of LH_2 must be delivered into the storage spheres at Pads A and B. To achieve this volume, a barge with 815,000-gal gross capacity is required. Allowing for 6-percent ullage, 6-percent water density safety fill factor, and approximately 44,000 gal in pressurization, boiloff, and other transfer losses, the proposed barge should deliver

670,000-gal of LH_2 into the pad storage spheres at KSC each round trip and permit leaving up to 3,000 gal of LH2 "heel" in each barge dewar.

The barge would be towed by a seagoing tug of 3,000 horsepower. The barge route is from the APCI plant on the Michoud Canal in New Orleans around the tip of Florida to Port Canaveral. With a towing speed of 8 miles per hour (mph), the 1,073-mile distance would be covered in 4-1/2 days. At Port Canaveral, a KSC tug would tow the barge through the locks and up the Banana River to the proposed barge docks at Pads A and B. As the Banana River channel is narrow, winding, and unlighted, barge traffic between Port Canaveral and KSC is restricted to daylight hours only. Travel time plus LH_2 offloading time at each pad would normally preclude 1-day turnaround. Allowing 2 days for barge movement and offloading operations in the KSC area and 1 day for barge loading at the APCI facility, the estimated barge round trip time is 12 days. A barge transportation model based on supporting 40 launches per year on the 12-day schedule is shown in Figure 1-2. Estimated time tables for development of barge equipment and facilities to support this option are shown in Figures 1-3 and 1-4.

APCI has barge loading facilities, however, some modification and rehabilitation is neeed to accommodate the proposed 815,000-gal barge. Implementation of the barge option at KSC would require dredging approximately 12,250 feet of channel to a width of 125 feet and a depth of 12 feet plus construction of barge dock facilities with 90 feet of lock clearance at each pad (Figures 1-5 and 1-6).

In addition, two pad access road bridges and one bastille railroad bridge, each with 90-foot spans, are required across the proposed barge channel. Minimum height clearance of the road bridges would be 50 feet to permit free passage of the unloaded barge with minimum draft. As the lock at Port Canaveral is 90 feet wide by 600 feet long with 55 feet of overhead clearance, no physical restrictions to barge movement should be encountered.

Additional construction required at each pad includes offloading and associated transfer lines. The offload transfer line from the barge dock to the LH_2 storage sphere at each pad would be approximately 400 feet in length. With valves, elbows and filters, the offload line would have an equivalent length of 450 feet. The offload line would consist of 8-inch VJ pipeline installed in conjunction with 12-inch vent lines and 10-inch Firex water deluge lines. At normal operating pressure, offloading of the 670,000 gal of LH_2 should require approximately 3 hours. Decreasing the offloading capacity to a 4-inch VJ line connected to the existing 4-inch input manifold line at Pads A and B would increase offloading time to more than 1? hours and would significantly increase offloading labor costs. The 8-inch VJ line, 12-inch vent line, and 10-inch Firex water deluge lines are also compatible with existing APCI facilities. To reduce transfer losses, the LH_2 barge would not be depressurized between unloading operations at Pads A and B.

The barge resupply cycle starts with both pad storage spheres containing 850,000 gal of LH_2. When a launch from Pad A occurs, storage in Sphere A would be reduced to 350,000 gal. Nine days later when a launch occurs from Pad B, storage would be reduced to 350,000 gal in Sphere B. The day following the second launch, a barge would arrive and offload 500,000 gal into Sphere A, filling the sphere to 850,000 gal. The remaining portion of the barge shipment would be deli ed into Sphere B. After every third barge delivery, each storage tank would contain 850,000 gal. As the maximum volume of LH_2 which can be removed from APCI facilities for barge onloading at one time is 844,700 gal (per APCI) no significant onloading delays should occur from a supply standpoint.

2.0 INVESTMENT COST

The estimated cost to design and build the proposed two-tank LH_2 barge was $8.6 million in 1976. Design and drawing estimates were provided by J. J. Henry Naval Architects, Inc. YFNB hull engineering estimates were provided by APCI and cryogenic tank and piping estimates were provided by the Chicago Bridge and Iron Company. Facilities construction estimates at Pads A and B were provided by KSC Design Engineering (DE). Projected investment cost to the time at which KSC contracts would be awarded for equipment and facilities is indicated as follows. Equipment cost estimates are escalated at 7 percent per year. Facilities investment costs are escalated in accordance with NASA Management Instruction (NMI) 7330.2.

- **Equipment Investment Cost**

	1976 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
LH_2 Barge (815,000-Gal Capacity)		
Design and Drawings	$ 300,000	
YFNB Hull Modifications	1,600,000	
Cryogenic Tanks and Piping	6,700,000	
Total	$8,600,000	$12,100,000

- **Cost Adjustment Factor (10 Percent)** $ 1,210,000

- **Facility Construction Cost**

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
Mobilization/Demobilization	$ 200,000	
Dredging Operations	1,430,000	
Weirs, Clearing, and Diking	373,300	
Bridges (Two Road/One Bastille*)	3,000,000	
Docking Facilities (Two)	1,250,000	
LH_2 Piping System (900 Feet)	1,440,000	
Total	$7,693,300	$12,460,000

Design Fee (6 Percent)	$ 748,000
APCI Dock Modification (KSC Estimate)	$ 50,000
Total Investment Cost	$26,568,000

* One bastille bridge at $1 million may not be required if rail delivery to Pad A is not essential.

3.0 OPERATING COST

The operating cost for LH_2 barge delivery includes the cost of a seagoing tug and a prorated share of the cost of the KSC tug. The 1977 lease rate for a seagoing tug is $1.00 per horsepower per day. Based on a 3,000-horsepower seagoing tug and a round trip time of 12 days, the seagoing tug cost per barge round trip would be $36,000. An additional charge of $3,000 for pilot services and insurance must be added for each seagoing tug round trip. KSC Transportation Services estimates $2,467 per trip as the prorata cost of the KSC tug. Projected to 1982, the operating cost per barge trip is estimated to be $58,162. Estimated total operating cost follows.

0 Barge Operating Cost

YEAR	COST/TRIP	LAUNCHES/ YEAR	BARGE TRIPS/ YEAR	COST/YEAR
1982	$ 58,162	13	10	$ 581,620
83	62,233	36	27	1,680,291
84	66,590	40	30	1,997,700
--	--	--	--	--
1991	106,929	40	30	3,207,870
		Total Operating Cost		$22,800,000

4.0 MAINTENANCE COST

Maintenance cost associated with the proposed LH_2 barge includes periodic cryogenic refurbishment, drydock servicing/corrosion control, and preventive/corrective maintenance of piping and instrumentation panels. AMKO Cryogenic Services recommends refurbishing of perlite insulation every 6 years at $6,000 per service plus corrosion control of the cryogenic tanks every 2 years at $0.45 per square foot. The U. S. Salvage Company Shipyards at Mobile, Alabama recommend the LH_2 barge be drydocked for 15 days every 2 years for hull corrosion control. Drydock costs are $0.30 per ton for hauling and $0.28 per ton per day for drydock time. Corrosion control for the barge hull is estimated at $1.35 per square foot for sandblasting and resurfacing (primer and paint). NSTL indicates the preventive/corrective maintenance costs for their barges average about $8,000 every 6 years; however, this figure is expected to double as the KSC LH_2 barge would be subjected to a salt water environment at all times. The 15-day drydock time loss every 2 years will require delivery of sufficient LH_2 for two STS launches by alternate means every 2 years. APCI delivery f.o.b. KSC using 13,000-gal mobile tankers is the logical alternative. For this reason, the LH_2 delivery cost for 96 mobile tanker loads (48 per launch) is added to the LH_2 barge maintenance cost for each year indicated. Cost factors and estimated maintenance cost for the proposed 700-ton LH_2 barge follow.

- **Maintenance Cost Factors**

	COST/YEAR (1977 DOLLARS)
Cryogenic Refurbishment	$ 1,000
Corrosion Control (LH_2 Tanks)	5,700
Drydock Operations	1,500
Corrosion Control (Hull)	24,300
Preventive/Corrective Maintenance	2,600
Barge Maintenance Cost	$35,100

- **Government Service Contract Cost (15 Percent)** $ 4,036

- **APCI Delivery f.o.b. KSC (1977)** $ 2,315/Tanker

- **Barge Maintenance Cost**

YEAR	COST/YEAR
1982	$ 49,229
83	52,675
* 84	438,154
85	60,308
* 86	501,618
87	69,047
* 88**	574,328
89	79,051
* 90	657,639
1991	90,506
Total Maintenance Cost	$2,573,000

* Cost includes 96 LH_2 deliveries by APCI 13,000-gal mobile tankers

** Cryogenic refurbishment year

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and barge operating functions. As opposed to Apollo, Security will be assumed by onsite KSC Safety and VO personnel. Road barricades and warning signs will be set up at area warning lights on each side of the LH_2 operational area and both Safety and VO personnel will monitor the burn pond. The Quality Assurance (QA) function will be performed by the VO lead technician. LH_2 offloading time through the 8-inch VJ line is estimated at 3 hours. Fire and Safety personnel are required in each area 1/2 hour prior to and following offloading operations. VO personnel are required in each area 1 hour prior to and following offloading operations to establish security, prepare the sites for operation, and to shut down the sites following operation. Estimated offloading cost follows.

- Cost per Barge Offloading Operation ($19.51/Hour 1982 Dollars)

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST/TRANSFER
Safety	1	4	4	$ 78
Fire	4	4	16	312
VO	3	5	15	293
Barge Operators	3	3	9	176
	Cost per Barge Transfer			$859

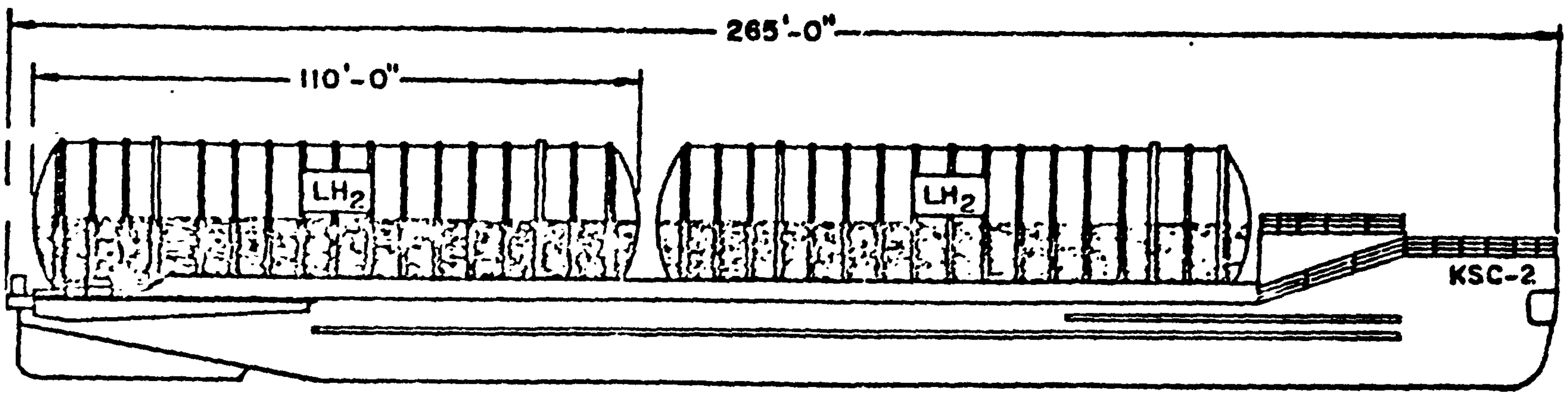
- **Barge Offloading Cost**

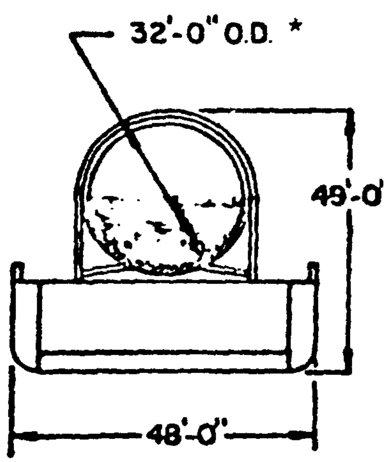
YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$ 858	12	$ 10,296
83	919	29	26,651
84	983	32	31,456
--	--	--	--
1991	1,578	32	50,496
		Total Offloading Cost	$360,000

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is reduced dramatically. For example, at 20 launches per year, no reduction in investment or maintenance costs would be realized, however, a 50-percent reduction in operating and offloading costs could be achieved. Transfer/efficiency losses would also be reduced by 50 percent except boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$26,568,000
Operating Cost	11,400,000
Maintenance Cost	2,573,000
Offloading Cost	180,000
Transfer/Efficiency Cost	7,732,000
TOTAL COST (20 LAUNCHES/YEAR	$48,453,000





SPECIFICATIONS

TANK INNER VESSEL	- ALUMINUM
TANK OUTER VESSEL	- CARBON STEEL
PRESSURE	- 50 POUNDS PER SQUARE INCH GAGE
CAPACITY	- 815,000 GAL GROSS
DRAFT	- 3.5' MINIMUM
	10.0' MAXIMUM

FIGURE 1-1
LH_2 BARGE

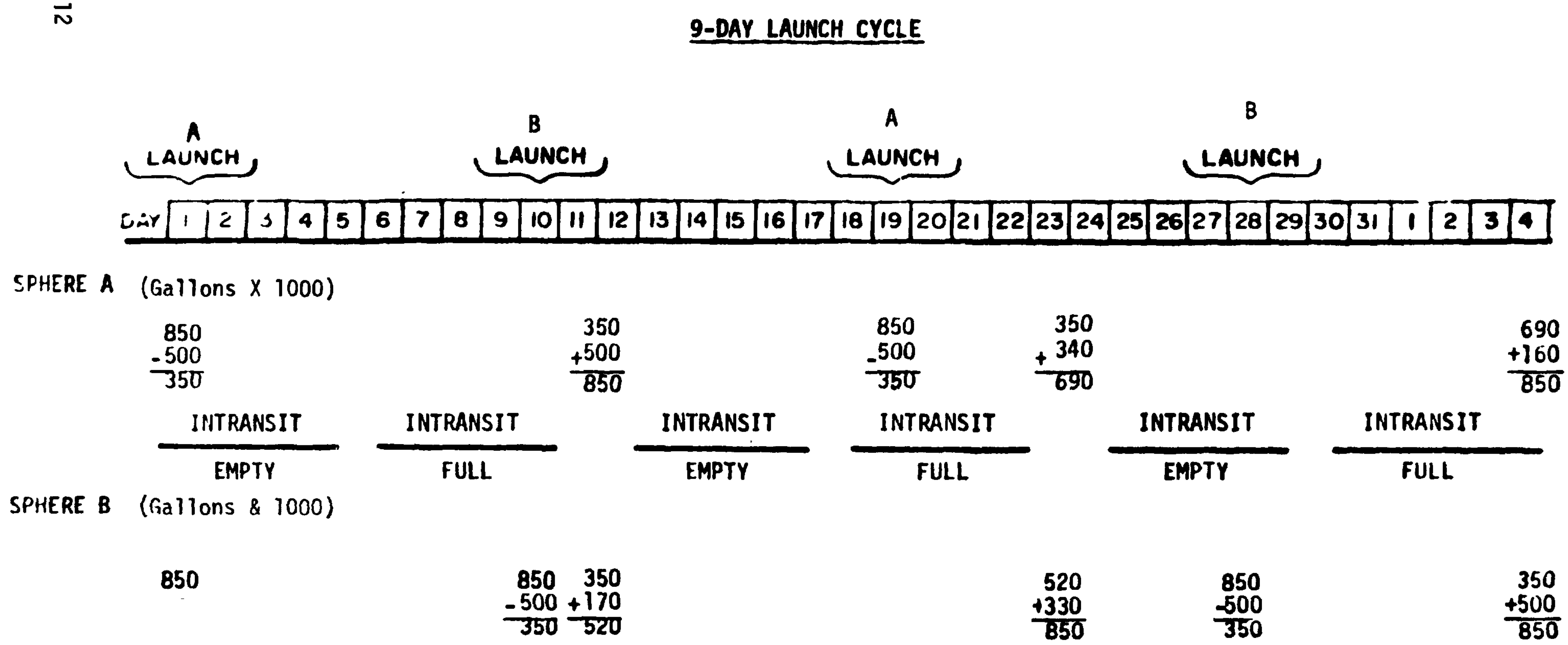


FIGURE 1-2

LH_2 BARGE TRANSPORTATION MODEL

BARGE VOLUME - 815,000 GAL (GROSS)
- 675,000 GAL (NET)

DELIVERIES/YEAR - 30

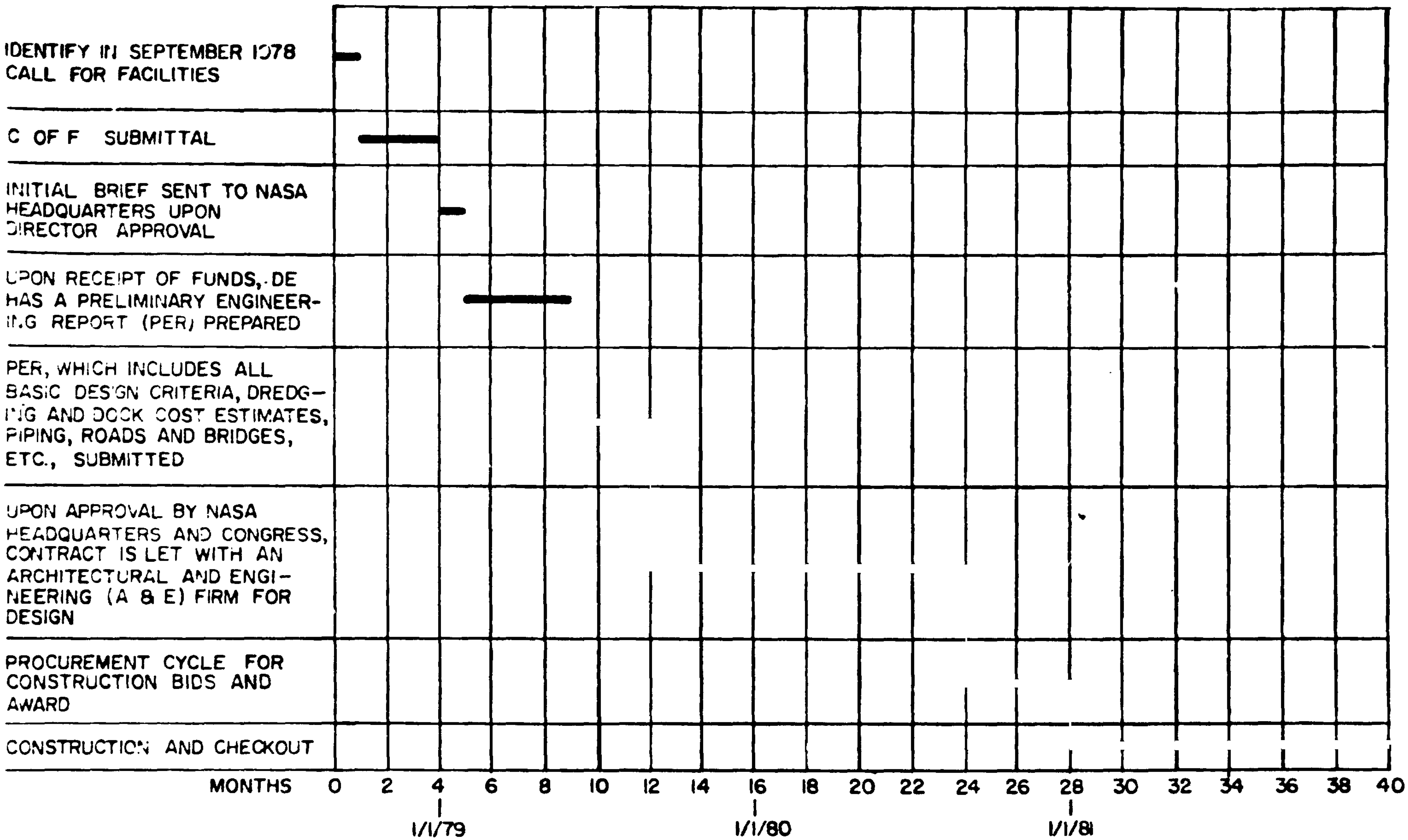


FIGURE 1-3

LH_2 BARGE FACILITIES DEVELOPMENT

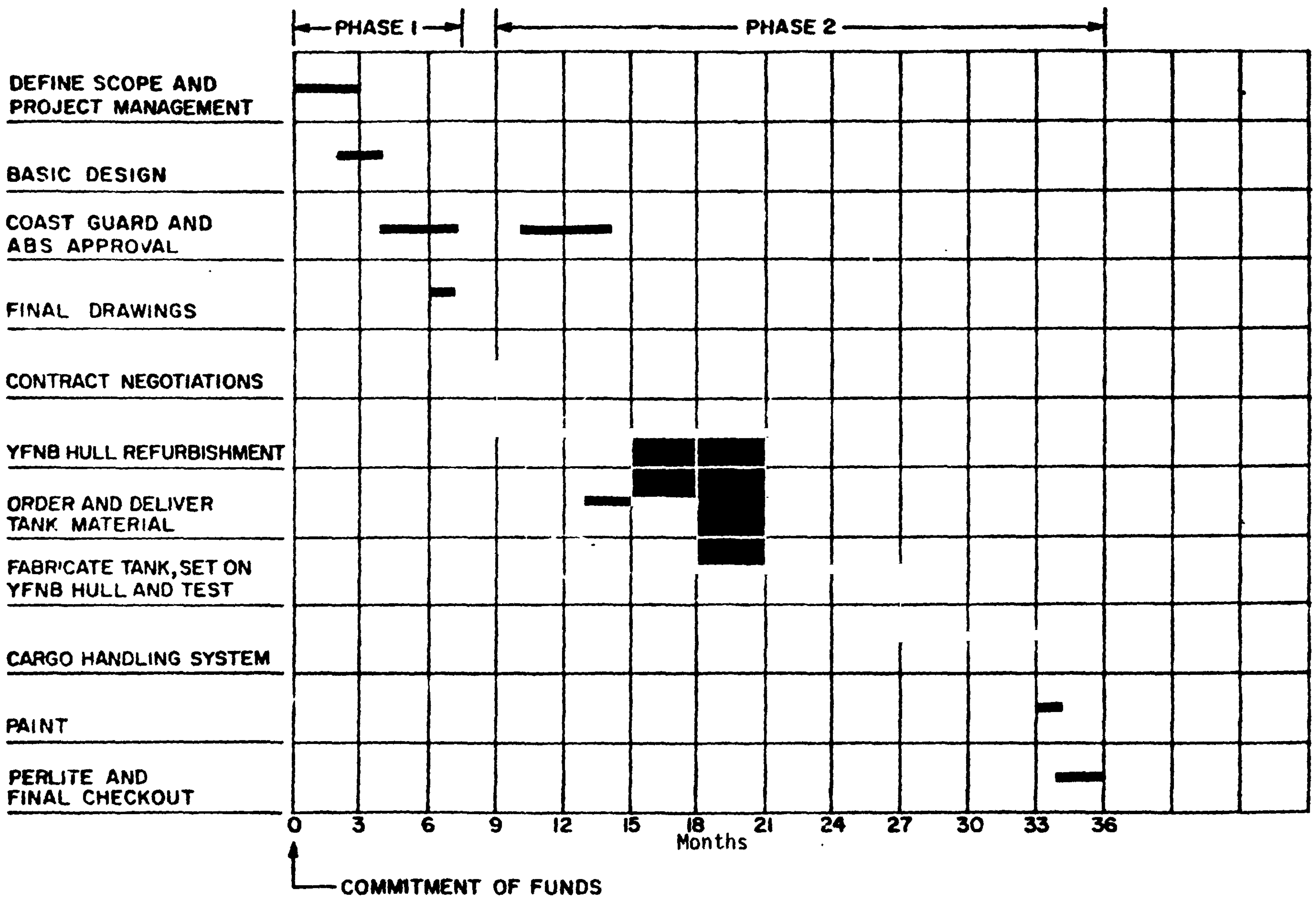


FIGURE 1-4

LH_2 BARGE DEVELOPMENT SCHEDULE

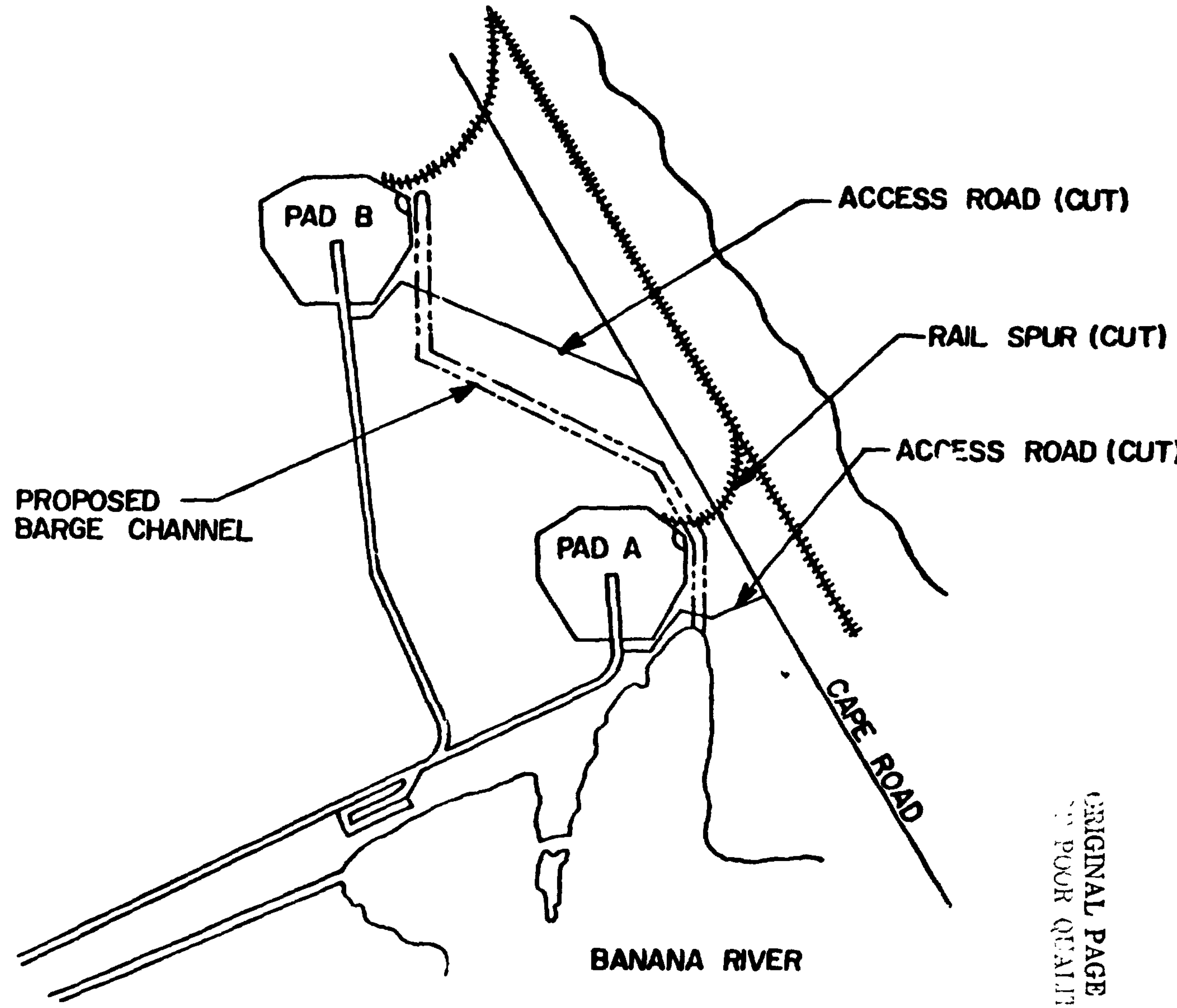


FIGURE 1-5

PROPOSED LH_2 BARGE CHANNEL TO PAD A & B LH_2 FACILITIES

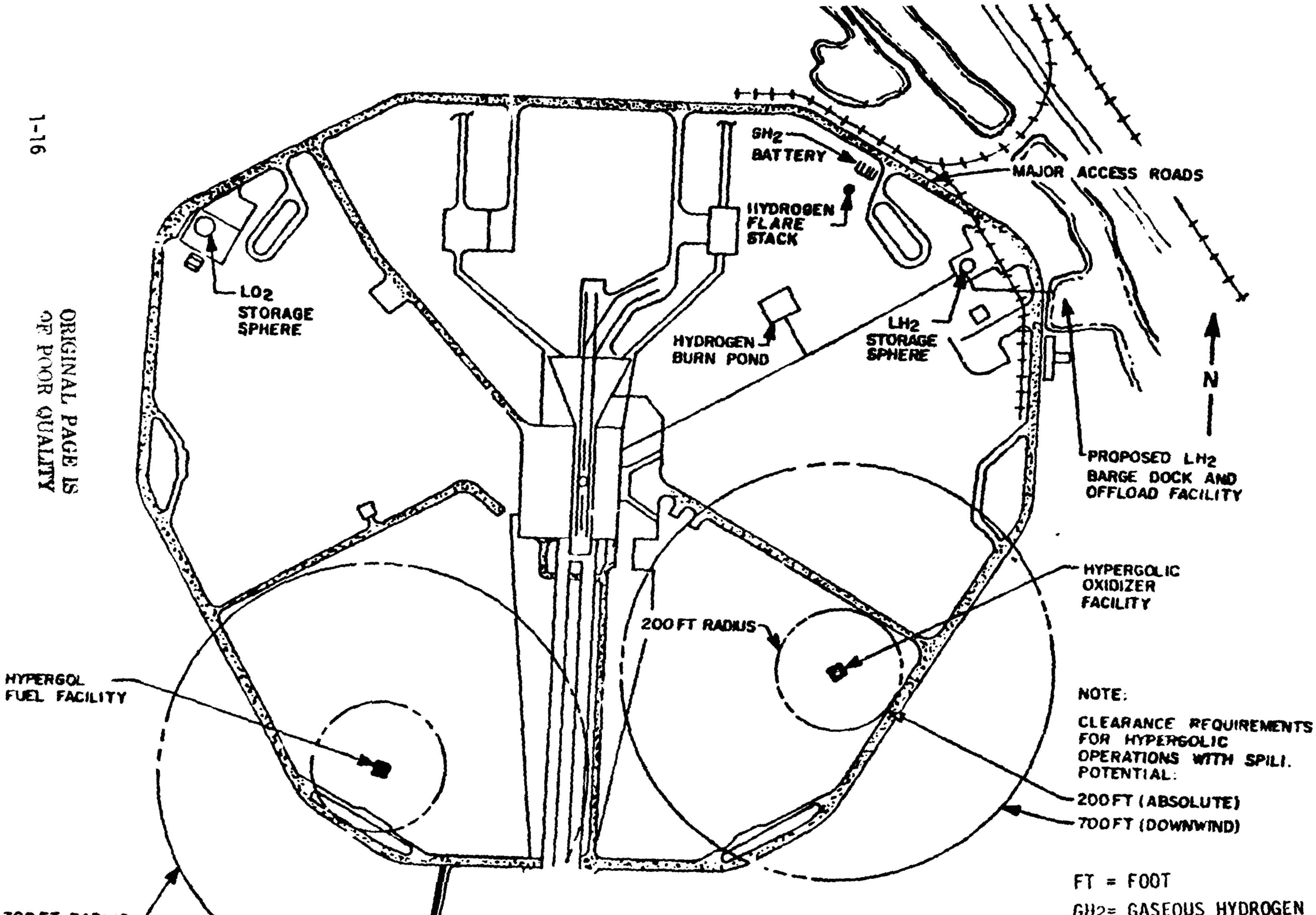


FIGURE 1-6

PROPOSED PAD LH2 DOCK FACILITIES LOCATION

APPENDIX 2

APPENDIX 2

OPTION 2 - BARGE/PAILCAR COMBINATION

1.0 CONCEPT OF OPERATION

Option 2 is based on LH_2 delivery by Government-owned barge directly from the APCI facility in New Orleans to Pad A as in Option 1. This option differs from Option 1 in that no barge channel or docking facility for Pad B would be constructed and transfer of LH_2 from the barge at Pad A to the Pad B storage sphere would be accomplished using four 34,000-gal LH_2 railcars moved by the KSC trackmobile.

To support 40 STS launches per year, 670,000 gal of LH_2 must be delivered into the storage spheres at Pads A and B each round trip. However, under this option, the increase in transfer/efficiency losses to approximately 69,500-gal which would result from double pressurization and offloading of the barge and railcars, requires that a barge with dewars of 840,000-gal gross capacity be used (Figure 2-1). A barge of this capacity would satisfy STS launch requirements and permit leaving up to 1,300 gal of LH_2 "heel" in each dewar after each delivery for reducing LH_2 tank chilldown losses during onloading operations.

The four LH_2 railcars planned for use under this option were built by Linde for NASA and are in covered storage at Lewis Research Center (Figure 2-2). Each railcar has a gross capacity of 36,100 gal and a stainless steel inner liner, carbon steel outer casing, mylar superinsulation, 0.5 percent per day boiloff rate, and a maximum 100-psig operating pressure. Each railcar has an 8-inch VJ supply line and standard NASA 2-inch bayonet couplings with two 20-foot flexible hoses for offloading. This 40-foot flexible offloading hose capability would permit connecting to the existing 2-inch LH_2 manifolds at Pads A and B with simultaneous offloading of up to four railcars. With the 34,000-gal railcar pressurized to 45 psig, offloading flow time should be approximately 1.5 hours per railcar offloading operation. No additional rail facilities or equipment would be required under this option.

APCI barge loading facilities would require some modification and rehabilitation as in Option 1, however, requirements for construction and facilities at KSC would be significantly reduced. Only 400 feet of barge channel would require dredging and only one dock and one road bridge with 50-foot height clearance would be required. LH_2 piping would also be reduced to 450 feet of 8-inch VJ line, 12-inch vent line, and 10-inch Firex water deluge lines. The proposed barge channel and rail access roads for this option are shown in Figure 2-3.

The barge resupply cycle starts with each pad storage sphere containing 850,000 gal of LH_2. When a launch from Pad A occurs, storage in Sphere A would be reduced to 350,000 gal. Nine days later when a launch occurs from Pad B, storage would be reduced to 350,000 gal in Sphere B. The day following the second launch, a barge would arrive and offload 500,000 gal by 8-inch VJ pipeline into Sphere A filling the sphere to 850,000 gal. The remaining portion of the barge shipment would be transferred to 34,000-gal (nominal) railcars and delivered into Sphere B. After every third barge delivery, each storage tank would contain 850,000 gal. The barge transportation model for this option is shown in Appendix 1, Figure 1-4. The barge and facility development schedules for this option are shown in Appendix 1, Figures 1-5 and 1-6.

2.0 INVESTMENT COST

The estimated cost to design and build the proposed 815,000-gal LH_2 barge is detailed in Appendix 1. For the 840,000-gal barge, a proportional cost increase of $260,000 is assumed. The cost of KSC facilities to support this option with dock facilities at Pad A only has been estimated at $3,050,000 by KSC Design Engineering (DE). Projected investment cost to the time at which KSC contracts would be awarded for equipment and facilities is estimated as follows.

- **Equipment Investment**

	1976 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
LH_2 Barge (840,000-Gal Capacity)	$8,760,000	$12,432,000
Four 34,000-Gal Railcars*	40,000	52,000
Total	$8,785,000	$12,484,000

- **Cost Adjustment Factor (10 Percent)** — $ 1,248,400

- **Facility Construction Cost**

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
Mobilization/Demobilization	$ 200,000	
Dredging Operations	500,000	
Bridge (One Road)	1,000,000	
Docking Facilities	625,000	
LH_2 Piping System (450 Feet)	725,000	
	$3,050,000	$ 4,941,000

Design Fee (6 Percent)	$ 296,500
APCI Dock Modification (Appendix 1)	$ 50,000
Total Investment Cc	$19,019,900

* Assumes the four existing LH_2 railcars owned by NASA will be made available to KSC. APCI estimates $40,000 initial rehabilitation cost for these four railcars (1976).

3.0 OPERATING COST

The operating cost for LH_2 delivery under this option includes the cost of a seagoing tug, a prorated share of the cost of the KSC tugs, and railcar and trackmobile costs at KSC. The estimated cost of the seagoing tug and KSC tug is detailed in Appendix 1. The cost of railcar transfer from the Pad A barge facility to the Pad B LH_2 storage sphere includes operator personnel and fuel costs for the KSC trackmobile. Pad B LH_2 requirements to support 20 launches per year at 500,000 gal per launch amount to 10,000,000 gal. This quantity must be provided from the 30 barge deliveries per year with an average of 10 railcar deliveries per barge trip required to maintain Pad B LH_2 sphere levels. Three personnel are required to operate the trackmobile and perform railcar switching functions. Each trackmobile round trip will move four railcars on a 3-hour round trip basis. At a 6.5-gal/hour consumption rate, the trackmobile fuel cost is estimated at $33.00 per barge delivery cycle. Operating cost factors and combined cost for barge and railcars follow.

- <u>Railcar/Trackmobile Operating Cost Factors</u>

Average LH_2 Volume/Delivery (Pad B).	333,300 Gal
*LH_2 Load/Railcar (6% Ullage)	33,900 Gal
Average Railcars/Barge Delivery.	10
Trackmobile Round Trips/Barge Delivery	3
Operator Cost (1982)	$19.51/Hour

* Increased load permitted for short haul with no boiloff assumed.

- Trackmobile/Railcar Operating Cost

YEAR	BARGE DELIVERIES	MAN-HOURS	OPERATOR COST	TRACKMOBILE COST	OPERATING COST
1982	10	90	$1,756	$ 330	$ 2,086
83	27	243	5,074	953	6,027
84	30	270	6,032	1,133	7,165
--	--	--	--	--	--
1991	30	270	9,685	1,820	11,505
	Trackmobile/Railcar Operating Cost				$ 78,800

- Barge Operating Cost (Appendix 1) $22,800,000

Total Operating Cost $22,878,800

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes corrosion control and cryogenic maintenance of barge and railcar LH_2 dewars and preventive and corrective maintenance of barge, railcar, and trackmobile equipment. Maintenance costs for the barge dewar and YFNB hull are detailed in Appendix 1. Useful maintenance data for the four 34,000-gal NASA LH_2 railcars are not available due to prolonged storage and limited use; however, the Linde Division, Union Carbide Corporation, which operates numerous LH_2 railcars estimates its 1977 average annual railcar maintenance cost at approximately $2,900. This estimate includes $1,250 every 2 years for DOT safety and instrumentation tests; $5,000 every 5 years for sandblasting, priming and painting; and $1,275 for preventive and corrective maintenance-related functions. Maintenance costs for the NASA trackmobile during the past 10 years have totalled $13,064. This total includes $2,096 for preventive maintenance, $5,565 for corrective maintenance, and $5,403 for materials. At the previous rate, projected maintenance costs escalated to 1991 for the trackmobile would be $33,685. As the trackmobile is getting older and the projected workload will increase dramatically, the estimated maintenance rate is doubled for this option. Estimated total maintenance cost follows.

- Railcar Maintenance Cost

YEAR	COST/RAILCAR	RAILCARS IN SERVICE	COST/YEAR
1982	$4,067	4	$ 16,268
83	4,353	4	17,408
84	4,656	4	18,624
--	--	-	--
1991	7,478	4	29,910
	Railcar Maintenance Cost		$ 225,000

- Barge Maintenance Cost (Appendix 1)* $2,573,000
- Trackmobile Maintenance Cost $ 41,000

Total Maintenance Cost $2,839,000

* Cost includes LH_2 deliveries by APCI with 13,000-gal LH_2 tankers f.o.b. KSC during barge drydock time as in Appendix 1.

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and barge operating functions as in Appendix 1. In addition, railcar offloading at Pad B will require additional Fire, Safety, and VO personnel while double offloading (barge at Pad A and railcar at LH_2 sphere at Pad B) is in progress. Total LH_2 offloading time for the Pad A sphere should average about 1.5 hours per barge trip. Total offloading time for the Pad B sphere should average about 9.5 hours per barge trip under this option. Fire and Safety personnel are required in each area 1/2 hour prior to and following offloading operations. VO personnel are required in each area 1 hour prior to and following offloading operations to establish security, prepare t sites for operation, and to shut down the sites following operation. Estimated cost factors and total offloading costs follow.

- Cost per Barge/Railcar Offloading Operation ($19.51/Hour 1982 Dollars)

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST/TRANSFER
Safety	2	12	24	$ 468
Fire	8	12	96	1,872
VO	6	13	78	1,521
Barge Operators	3	12	36	702
	Cost per Barge/Railcar Transfer			$4,563

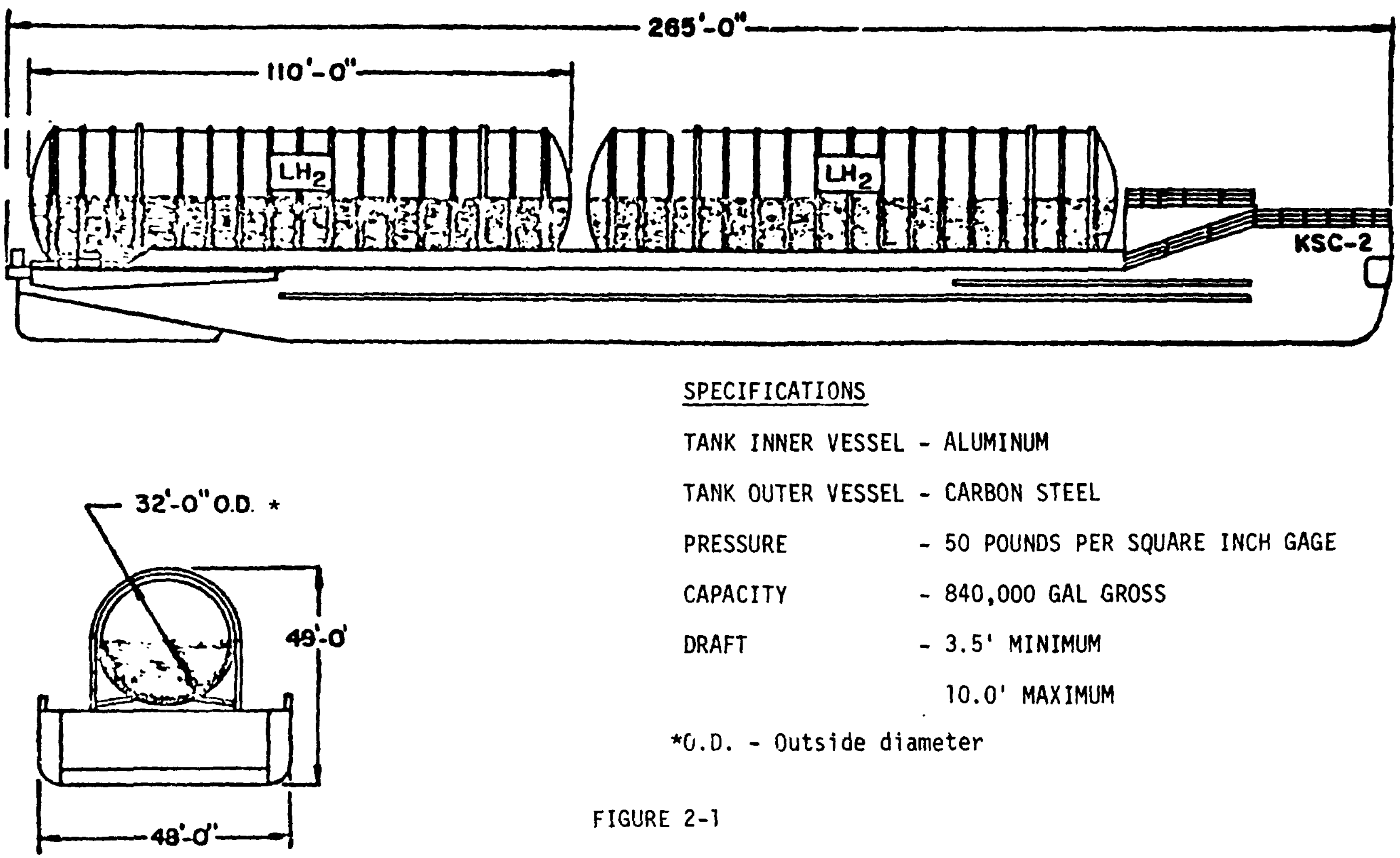
- **Barge/Railcar Offloading Cost**

YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$4,563	10	$ 45,630
83	4,883	27	131,841
84	5,224	30	156,720
--	--	--	--
1991	8,388	30	251,640
		Total Offloading Cost	$1,785,500

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is reduced dramatically. For example, at 20 launches per year, no reduction in investment or maintenance costs would be realized, however, a 50-percent reduction in operating and offloading costs could be achieved. As in Appendix 1, transfer/efficiency losses would also be reduced by 50 percent except boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$19,019,900
Operating Cost	11,439,400
Maintenance Cost	2,839,000
Offloading Cost	892,700
Transfer/Efficiency Cost	11,209,300
TOTAL COST (20 LAUNCHES/YEAR	$45,400,300



SPECIFICATIONS

TANK INNER VESSEL	- ALUMINUM
TANK OUTER VESSEL	- CARBON STEEL
PRESSURE	- 50 POUNDS PER SQUARE INCH GAGE
CAPACITY	- 840,000 GAL GROSS
DRAFT	- 3.5' MINIMUM
	10.0' MAXIMUM

*O.D. - Outside diameter

FIGURE 2-1

LH_2 BARGE

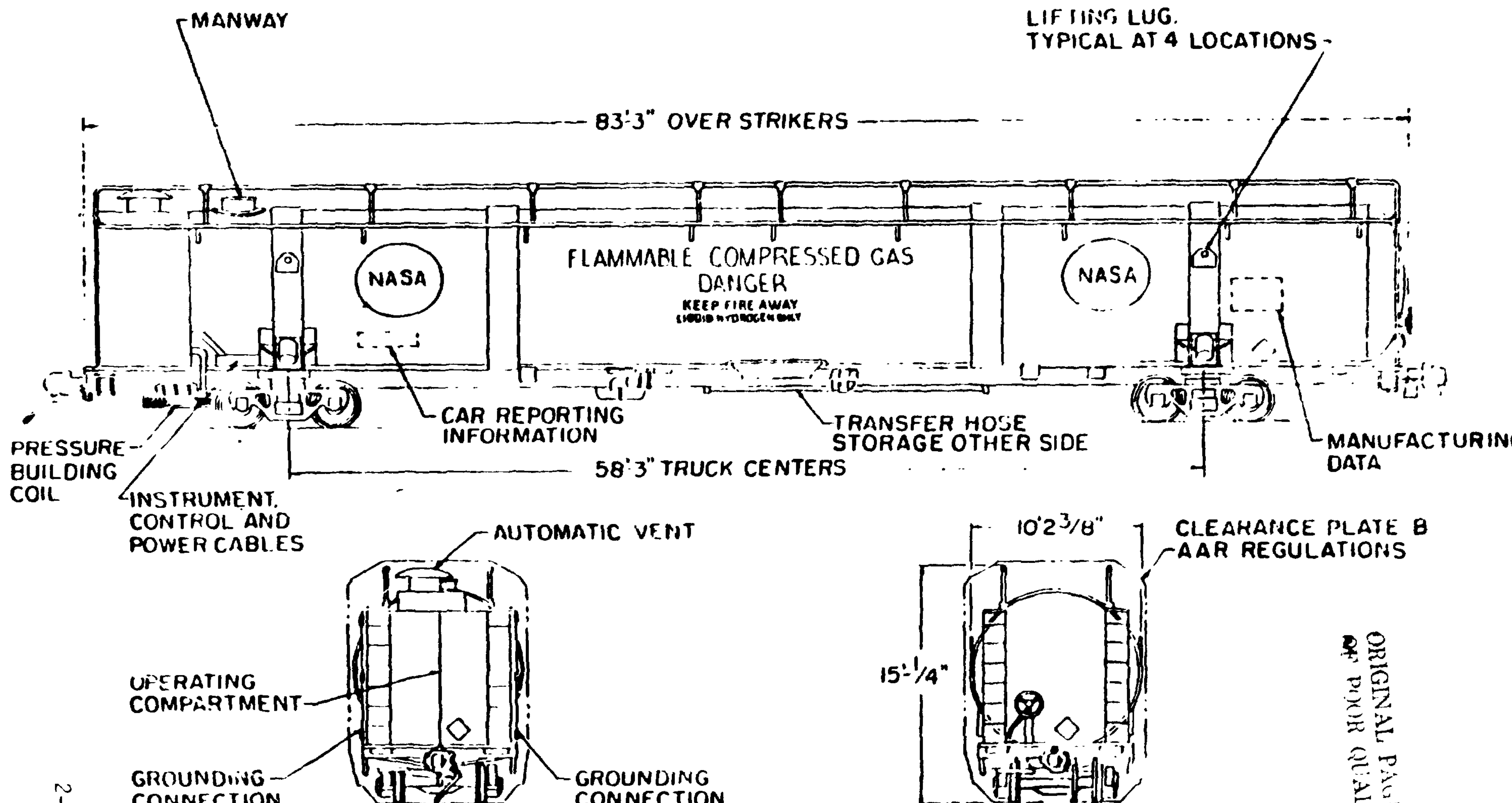


FIGURE 2-2
34,900 Gallon Liquid Hydrogen Tank Car

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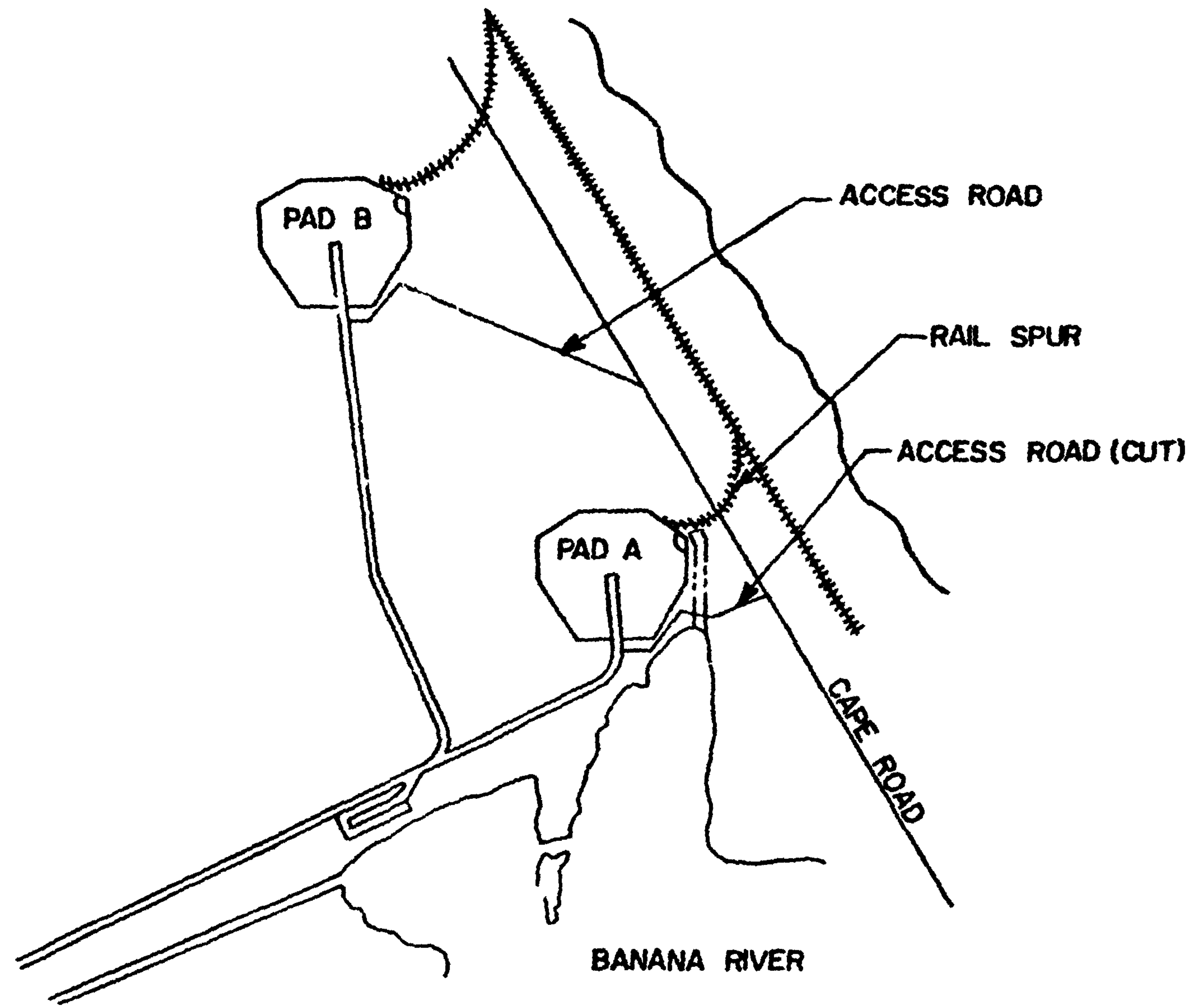


FIGURE 2-3

BARGE OPTION RAIL ACCESS TO PADS A AND B

APPENDIX 3

APPENDIX 3

OPTION 3 - BARGE/PIPELINE COMBINATION

1.0 CONCEPT OF OPERATION

Option 3 is based on LH_2 delivery by Government-owned barge directly from the APCI facility in New Orleans to Pad A as in Option 1. This option differs from Option 1 in that no barge channel or docking facility for Pad B would be constructed, and transfer of LH_2 from the barge dock at Pad A to the Pad B storage sphere would be accomplished using cross-country, VJ pipeline.

The pipeline option would permit rapid offloading of the LH_2 barge to Pads A and B and produce a significant reduction in offloading time and cost. The pipeline would consist of an 8-inch stainless steel inner line surrounded by an outer jacket with full vacuum in the annular space between the lines to reduce transfer line chill-down losses. The 8-inch inner pipeline would be designed for a minimum internal pressure of 120 psig coincident with full vacuum in the annular space, and a design temperature range of minus 423 degrees fahrenheit (° F) to plus 200° F. At 45 psig, LH_2 offloading of the barge could be accomplished in approximately 3 hours.

As in Options 1 and 2, 40 STS launches per year must be supported and 670,000 gal of LH_2 must be delivered into the storage spheres at Pads A and B each round trip. However, under this option, losses of approximately 58,900-gal per delivery resulting from barge and pipeline transfer/efficiency losses require that a barge with dewars of 830,000-gal gross capacity be used (Figure 3-1). A barge of this capacity would provide STS launch requirements and permit leaving up to 2,200 gal of LH_2 "heel" in each dewar after each delivery to reduce tank chilldown losses during onloading operations.

The proposed pipeline would be approximately 9,000 feet in length. That portion of the pipeline from the barge offloading terminal to the Pad A LH_2 sphere would be 450 feet in length. That portion of the pipeline from the Pad A LH_2 sphere to the Pad B sphere would be approximately 8,500 feet in length (Figures 3-2 and 3-3).

Both Pad A and Pad B would require installation of 12-inch vent lines and 10-inch Firex water deluge lines in conjunction with the 8-inch VJ pipelines.

APCI barge loading facilities would require limited modification as described in Appendix 1. KSC barge channel and facilities construction would be identical to that described in Appendix 2 except that construction of the LH_2 pipeline from Pad A to Pad B would be required.

The barge/pipeline resupply cycle starts with each pad storage sphere containing 850,000 gal of LH_2. When a launch from Pad A occurs, storage in Sphere A would be reduced to 350,000 gal. Nine days later, when a launch occurs from Pad B, storage would be reduced to 350,000 gal in Sphere B. The day following the second launch, a barge would arrive and offload 500,000 gal by pipeline into Sphere A filling the sphere to 850,000 gal. The remaining portion of the barge shipment would be delivered by pipeline into Sphere B. After every third barge delivery, each storage tank would contain 850,000 gal of LH_2. The barge transportation model for this cption is shown in Appendix 1, Figure 1-4. The equipment and facilities timetables for this option are shown in Appendix 1, Figures 1-5 and 1-6.

2.0 INVESTMENT COST

The estimated cost to design and build the proposed 815,000-gal LH_2 barge is detailed in Appendix 1. For the 830,000-gal barge, a proportional cost increase of $155,000 is assumed. The cost of KSC facilities to support this option with barge docking facilities at Pad A only is detailed in Appendix 2. KSC Design Engineering (DE) has estimated the contract cost of constructing the LH_2 pipeline to Pads A and B at $1,000 per linear foot. This price includes line materials, landfill, support foundations, expansion loops, chilldown stations, valves, terminations, instrumentation, vent and water deluge systems, and labor. Projected investment cost to the time at which KSC contracts would be awarded for equipment and facilities is estimated as follows.

- **Equipment Investment**

	1976 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
One Barge (830,000-Gal Capacity)	$ 8,758,000	$12,284,000

- **Cost Adjustment Factor (10 Percent)** — $ 1,228,400

- **Facility Construction Cost**

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
Mobilization/Demobilization	$ 200,000	
Dredging Operations	500,000	
Bridge (One Road)	1,000,000	
Docking Facilities	625,000	
LH_2 Piping System (9,000 Feet)	9,000,000	
Total	$11,325,000	$18,346,500

- **Design Fee (6 Percent)** — $ 1,100,800
- **APCI Dock Modifications (Appendix 1)** — 50,000

Total Investment Cost — $33,009,700

3.0 OPERATING COST

The operating cost for LH_2 delivery under this option includes the barge-related costs of a seagoing tug and a prorated share of the cost of the KSC tug, plus KSC pipeline operating cost. Estimated barge operating cost is detailed in Appendix 1. Pipeline operating cost includes the hourly wage of Vehicle Operations (VO) personnel to control valves and monitor LH_2 flow during barge offloading operations. Estimated offloading flow is 3 hours with VO personnel required 1 hour prior to and following offloading. Total estimated operating cost follows.

- **Pipeline Operating Cost**

YEAR	MAN-HOURS	COST/MAN-HOUR	COST/YEAR
1982	100	$19.51	$ 1,951
83	270	20.88	5,637
84	300	22.34	6,702
--	--	--	--
1991	300	35.87	10,761
		Pipeline Operating Cost	$ 76,300

- **Barge Operating Cost (Appendix 1)** $22,800,000

Total Operating Cost $22,876,300

4.0 MAINTENANCE COST

Maintenance Cost associated with this option includes barge corrosion control, special drydock costs, periodic cryogenic tank refurbishment, and pipeline repair. Estimated barge maintenance cost is detailed in Appendix 1. Estimated pipeline maintenance is based on hourly wage requirements for a single operator/maintenance man to perform readings, pull vacuums, and otherwise maintain the pipeline. Twenty hours per week are assumed to be adequate for this task. Total estimated maintenance cost for this option follows.

- Pipeline Maintenance Cost

YEAR	MAN-HOURS	COST/MAN-HOUR	COST/YEAR
1982	1,040	$19.51	$ 20,290
83	1,040	20.88	21,715
84	1,040	22.34	23,233
--	--	--	--
1991	1,040	35.87	37,305
	Pipeline Maintenance Cost		$ 280,300

- Barge Maintenance Cost (Appendix 1) $2,573,000

Total Maintenance Cost $2,853,300

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, VO, and barge operating functions as in Appendix 1. However, upon completion of LH_2 offloading at Pad A, these personnel must remain at that location for barge offloading to Pad B. Offloading at Pad B will require two additional pipeline operating personnel for ar .ɔximately 2 hours each. These two additional personne, are required for controlling valves, monitoring pressures, flow rates, etc. Estimated offloading cost factors and total offloading cost for this ontion follow.

- Cost per Barge Transfer Operation

FUNCTION	PERSONNEL PAD A	PERSONNEL PAD B	HOURS/ OPERATION	TOTAL MAN-HOURS	COST AT $19.51/ MAN-HOUR (1982)
Safety	1	0	4	4	$ 78
Fire	4	0	4	16	312
VO	3	2	5	25	487
Barge Operators	3	0	3	9	176
			Cost per Pipeline Transfer		$1,053

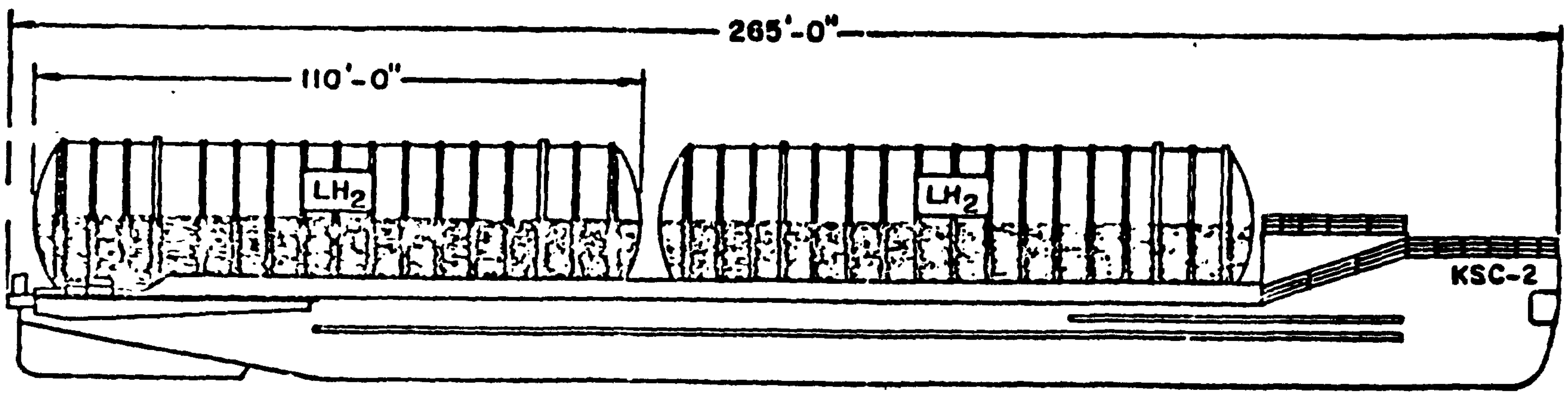
• **Barge/Pipeline Offloading Cost**

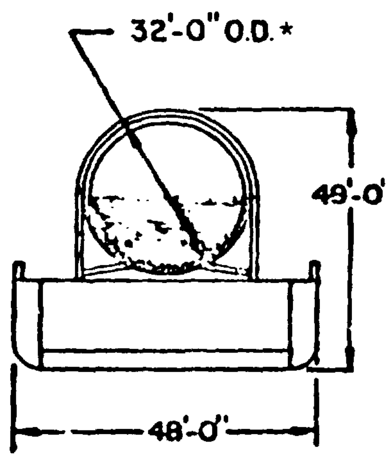
YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$1,053	10	$ 10,530
83	1,125	27	30,402
84	1,205	30	36,150
--	--	--	--
1991	1,935	30	58,050
	Total Offloading Cost		$411,823

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is reduced dramatically. For example, at 20 launches per year, no reduction in investment or maintenance costs would be realized; however, a 50-percent reduction in operating and offloading costs could be achieved. As in Option 1, transfer/efficiency losses would also be reduced by 50 percent except boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$33,009,700
Operating Cost	11,438,100
Maintenance Cost	2,853,000
Offloading Cost	205,900
Transfer/Efficiency Cost	9,602,000
TOTAL COST (20 LAUNCHES/YEAR)	$57,108,700





SPECIFICATIONS

TANK INNER VESSEL	- ALUMINUM
TANK OUTER VESSEL	- CARBON STEEL
PRESSURE	- 50 POUNDS PER SQUARE INCH GAGE
CAPACITY	- 830,000 GAL GROSS
DRAFT	- 3.5' MINIMUM
	10.0' MAXIMUM

*O.D. = Outside diameter

FIGURE 3-1

LH_2 BARGE

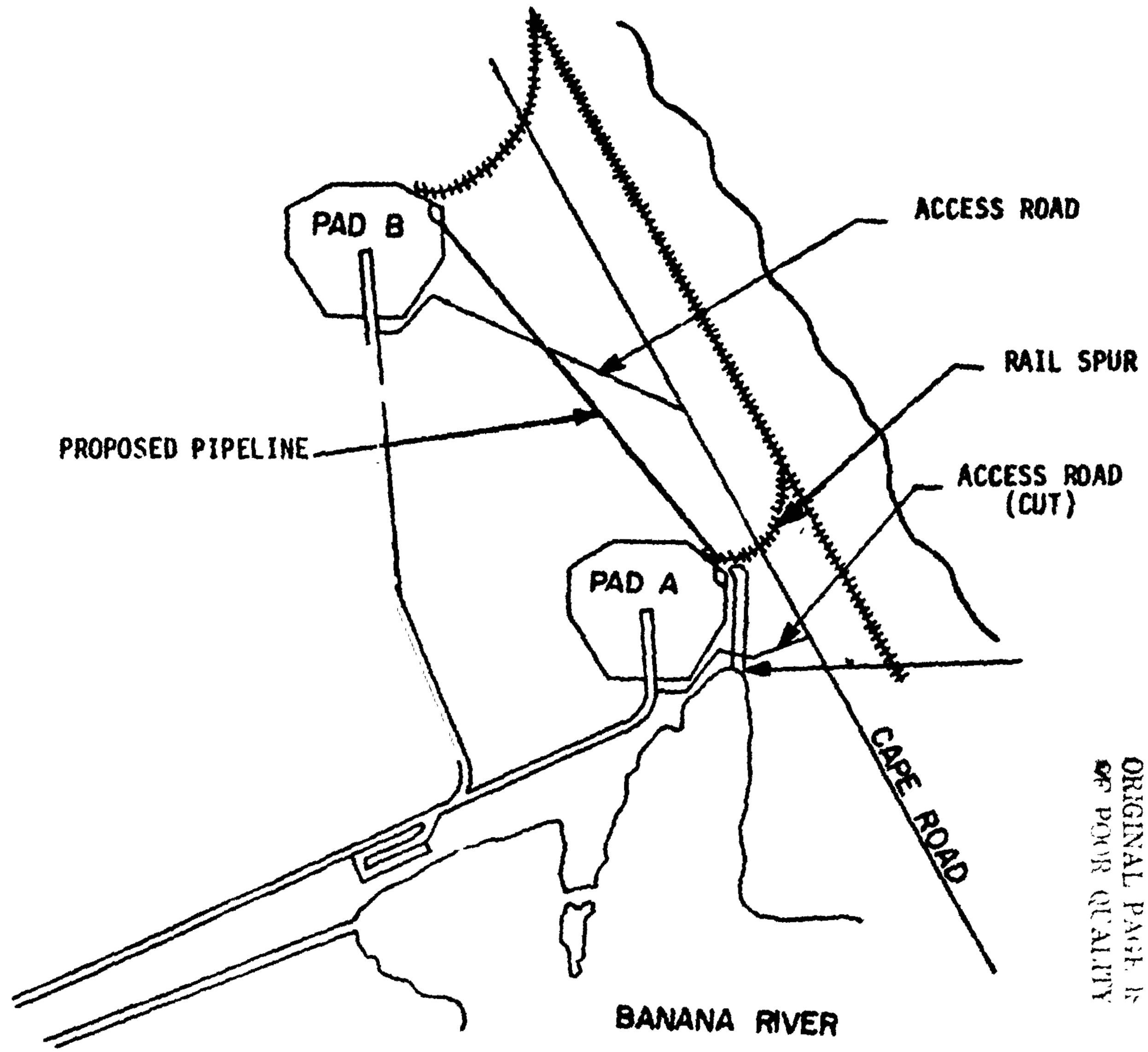


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FIGURE 3-2

PROPOSED LH_2 BARGE - PIPELINE SITE PLAN

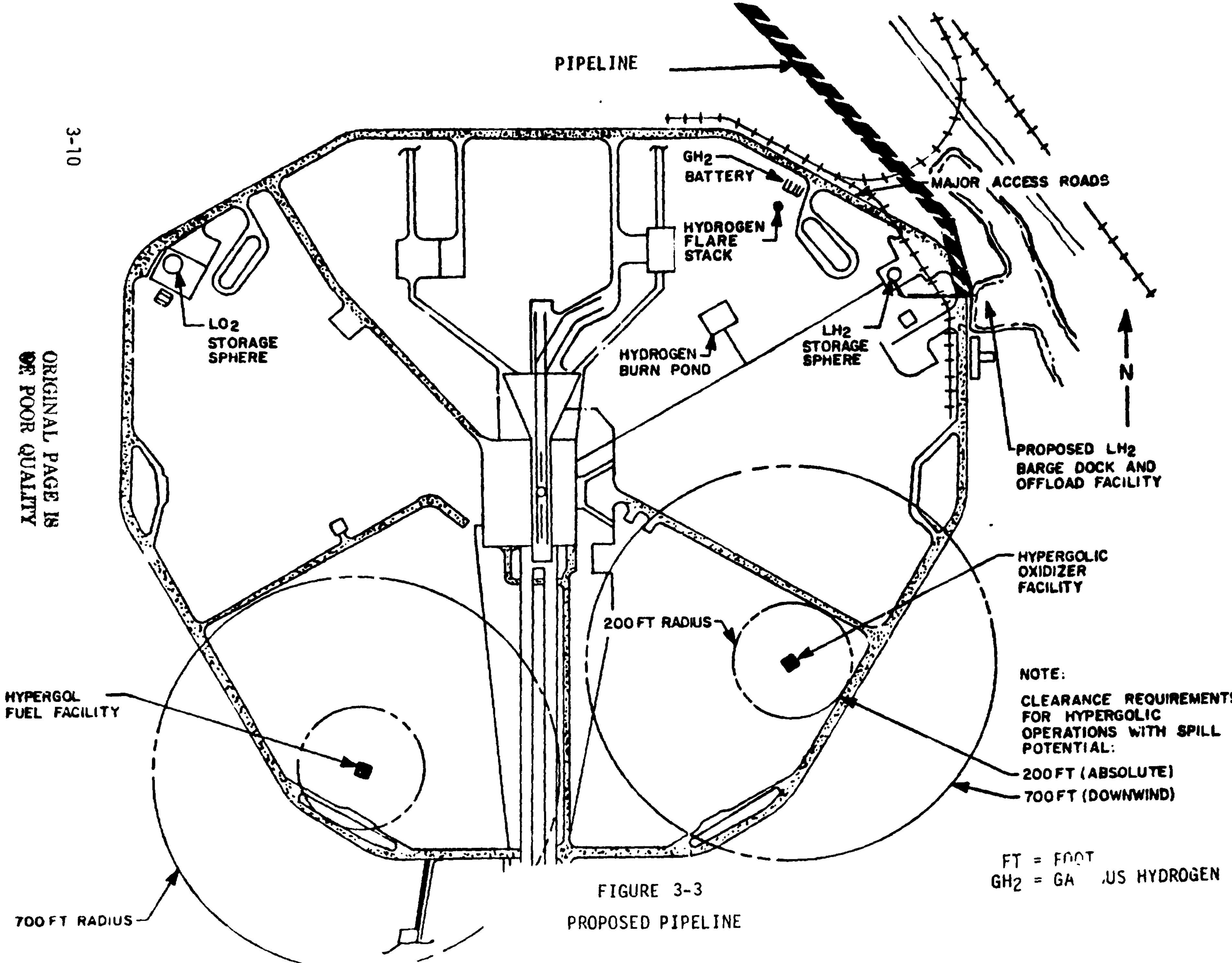

FIGURE 3-3

PROPOSED PIPELINE

APPENDIX 4

APPENDIX 4

OPTION 4 - BARGE/MOBILE TANKER COMBINATION

1.0 CONCEPT OF OPERATION

Option 4 is based on LH_2 delivery by Government-owned barge directly from the APCI facility in New Orleans to Pad A as in Option 1. This option differs from Option 1 in that no barge channel or docking facility for Pad B would be constructed, and transfer of LH_2 from the barge at Pad A to the Pad B storage sphere would be accomplished using existing KSC-owned 13,000-gal LH_2 mobile semitrailer tankers moved by GSA tractors.

To support 40 STS launches per year, 670,000 gal of LH_2 must be delivered into the storage spheres at Pads A and B each round trip. However, the increase in transfer/efficiency losses to approximately 70,132 gal resulting from double pressurization and offloading of the barge and mobile tanker combination under this option requires that a barge with dewars of 840,000-gal gross capacity be used (Appendix 2, Figure 2-1). A barge of this capacity would satisfy STS launch requirements and permit leaving up to 1,000 gal of LH_2 "heel" in each dewar after each delivery.

The 13,000-gal LH_2 mobile tankers planned for use under this option were built for NASA by APCI (Figure 4-1). Four tankers are presently in use by APCI at New Orleans and three are located at KSC. Under this option, all seven mobile tankers would be returned to KSC and would be operated in two serials for onloading from the barge and offloading into the Pad B LH_2 sphere manifold. The mobile tankers have a 13,250-gal gross capacity, stainless steel inner liner, carbon steel outer shell, mylar superinsulation, .75-percent-per-day boiloff rate, and a 45-psig maximum operating pressure. At 45 psig, the estimated onloading and offloading time would be approximately 1.5 hours plus 1.0 hour travel time. Boiloff losses from the barge to Pad B would be negligible and would permit loading 12,400-gal of LH_2 into each tanker for the short haul to Pad B. Each mobile tanker is equipped with the NASA, standard 2-inch bayonet fitting and the LH_2 spheres at Pads A and B each have sufficient 2-inch loading manifold bayonet connectors and parking spaces for simultaneous offloading of up to five mobile tankers.

Because of the daylight hour restriction on the Banana River and the need to reduce offloading costs, transfer time from the barge to mobile tankers is critical. To provide 500,000 gal of LH_2 to the Pad B sphere, forty-one mobile tanker deliveries with a maximum 12,400-gal LH_2 load per tanker are required. With a 2.5-hour turn-around time, the use of all seven KSC 13,000-gal mobile tankers is considered essential to permit offloading the barge and transfer of a maximum load of LH_2 to the Pad B sphere in less than 18 hours. No new construction for mobile tankers would be required, however, APCI barge loading facilities would require modification as described in Appendix 1. KSC barge channel and facilities required for this option would be identical to those described in Option 2. The proposed barge channel and access road for this option are shown in Figure 4-2.

The barge resupply cycle for this option starts with each pad storage sphere containing 850,000 gal of LH_2. When a launch from Pad A occurs, storage in Sphere A would be reduced to 350,000 gal. Nine days later when a launch occurs from Pad B, storage would be reduced to 350,000 gal in Sphere B. The day following the second launch, a barge would arrive and offload 500,000 gal by 8-inch VJ pipeline into Sphere A filling the sphere to 850,000 gal. The remaining portion of the barge shipment would be transferred to 13,000-gal (nominal) mobile tankers and delivered into Sphere B. After every third barge delivery, each storage tank would contain 850,000 gal. The barge transportation model for this option is shown in Appendix 1, Figure 1-4. The barge and facility development schedules for this option are shown in Appendix 1, Figures 1-5 and 1-6.

2.0 INVESTMENT COST

The investment cost associated with this option includes procurement and construction of the proposed 840,000-gal barge and associated docking facilities for Pad A as detailed in Appendix 2, plus procurement of seven dedicated GSA tractors. This option assumes the four NASA-owned 13,000-gal LH_2 mobile tankers at APCI would be returned and that all seven mobile tankers would be available at no additional cost. GSA estimates the 1977 cost of tractors with sleeper cabs t $41,000 each. Estimated total investment cost to the time at which KSC contracts would be awarded follows.

- Equipment Investment

	1976 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
One Barge (840,000-Gal Capacity)	$8,760,000	$12,432,000
*Seven GSA Tractors		376,200
Total		$12,808,200

- Cost Adjustment Factor (10 Percent) — $ 1,280,800

- Facility Construction Cost

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
Pad A Barge Facility	$3,050,000	$ 4,941,000
• Design Fee (6 Percent)		296,500
• APCI Dock Modification (Appendix 1)		50,000
Total Investment Cost		$19,376,500

3.0 OPERATING COST

The operating cost for LH_2 delivery under this option includes the cost of the LH_2 barge plus the cost of the GSA tractors and mobile tankers at KSC. The estimated cost of LH_2 barge operations is detailed in Appendix 1. The cost of the 13,000-gal mobile tanker transfer from the Pad A barge facility to the Pad B LH_2 storage sphere includes operator personnel and rental costs for the GSA tractors. Pad B LH_2 requirements to support 20 launches per year at 500,000 gal per launch equate to 10,000,000 gal. This quantity must be provided from 30 barge deliveries per year with an average of 27 mobile tanker deliveries per barge trip required to maintain

* Assumes seven GSA tandem-axle, diesel tractors procured for dedicated support of this option.

C-2

Pad B LH_2 sphere levels. The GSA rate for tractors capable of hauling the 13,000-gal mobile tankers is $0.28 per mile plus a daily prorata share of a $240 monthly service charge. One operator is required for each of the seven GSA tractor/mobile tanker combinations. The round trip delivery time is 2.5 hours per mobile tanker load. Estimated operating cost factors and combined barge/mobile tanker cost follows.

- **Mobile Tanker Operating Cost Factors**

  Average LH_2 Volume/Delivery (Pad B) . . . . 333,300 Gal

  LH_2 Load/13,000-Gal Mobile Tanker (6% Ullage) . . 12,400 Gal

  Average Mobile Tanker Loads/Barge Delivery. 27

  Average Mobile Tanker Operator Cost/Barge Delivery (1982) $1,317

  Average GSA Tractor Cost/Barge Delivery (1982). . . . . $ 147

- **Mobile Tanker Operating Cost**

YEAR	BARGE TRIPS	MANPOWER COST/TRIP	GSA TRUCK COST/TRIP	COST/YEAR
1982	10	$1,317	$147	$ 14,640
83	27	1,409	157	42,282
84	30	1,507	168	50,250
--	--	--	--	--
1991	30	2,419	270	80,670
		Mobile Tanker Operating Cost		$ 572,500

- Barge Operating Cost (Appendix 1) $22,800,000

  Total Operating Cost $23,372,500

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes barge corrosion control and refurbishment expenses combined with 13,000-gal mobile tanker maintenance functions including periodic cryogenic tank refurbishment, pneumastat tests, and KSC Administration and Scheduling (A&S) costs. The estimated cost of barge maintenance is detailed in Appendix 1. Consultation with AMKO Cryogenic Services and APCI indicates that LH_2 mobile tankers should be refurbished every 5 years. Current quotations from APCI indicate a cost of $4,500 per tanker for this service. Examination of KSC maintenance records for LH_2 mobile tankers for 1976 indicates an average of $2,285 per tanker was expended (for all expenses except refurbishment) and that A&S costs were approximately $10,700. The estimated maintenance cost factors and maintenance cost for this option, with escalation of these costs to a 1982 time of reference, follow.

- Mobile Tanker Maintenance Cost Factors (1976 Dollars)

	COST/YEAR
Preventive Maintenance 110 Man-Hours @ $13.00/Man-Hour	$1,430
Corrective Maintenance 20.0 Man-Hours @ $13.00/Man-Hour	260
Materials (Includes Cleaning)	270
Major Refurbishment - $4,500 Every 5 Years	900
Pneumastat at 25 Man-Hours/Year @ $13.00/Man-Hour	325

- **Mobile Tanker Maintenance Cost**

YEAR	MAINTENANCE/ TANKER/YEAR	TANKERS IN SERVICE	MAINTENANCE TOTAL	KSC A&S COST/YEAR	COST/YEAR
1982	$4,780	7	$33,460	$16,058	$ 49,518
83	5,115	7	35,802	17,182	52,984
84	5,473	7	38,311	18,385	56,696
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1991	8,788	7	61,515	29,522	91,037
	Mobile Tanker Maintenance Cost				$ 684,000
Barge Maintenance Cost (Appendix 1)					$2,573,000
	Total Maintenance Cost				$3,257,000

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and barge operating functions as in Appendix 1. In addition, simultaneous offloading of mobile tankers at Pad B will require additional Fire, Safety, and VO personnel while barge off-loading at Pad A is in progress. Total LH_2 offloading time for the Pad A sphere should average about 1.5 hours per barge trip. Total offloading time to the 13,000 gal mobile tankers for the Pad B sphere should average about 16.5 hours per barge trip under this option. Fire and Safety personnel are required in each area 1/2 hour prior to and following offloading operations. VO personnel are required in each area 1 hour prior to and following offloading operations to establish security, prepare the sites for operation, and shut down the sites following operations. Estimated cost factors and total offloading costs follow.

- **Cost per Barge/Mobile Tanker Offloading Operation ($19.51/Hour) 1982 Dollars)**

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST/TRANSFER
Safety	2	19	38	$ 741
Fire	8	19	152	2,965
VO	6	20	120	2,342
Barge Operators	3	19	57	1,112
	Cost per Barge/Mobile Tanker Transfer			$7,160

- **Barge/Mobile Tanker Offloading Cost**

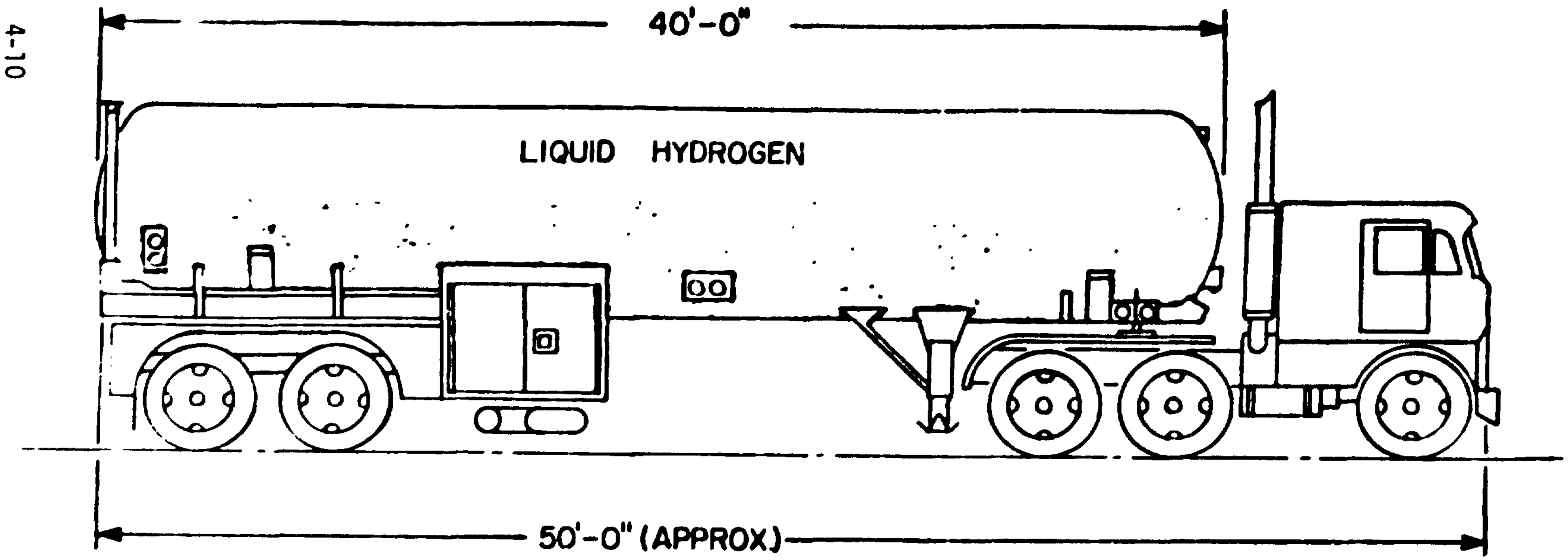
YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$7,160	10	$ 71,600
83	7,660	27	206,820
84	8,196	30	245,880
--	--	--	--
1991	13,161	30	394,830
		Total Offloading Cost	$2,801,097

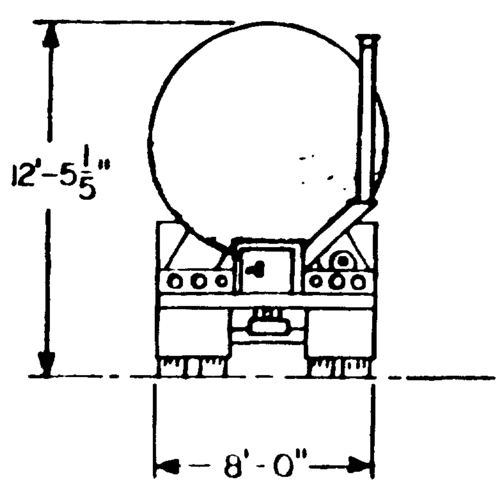
6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is reduced dramatically. For example, at 20 launches per year, no reduction in investment or maintenance costs would be realized, however, a 50-percent reduction in operating and offloading costs could be achieved.

As in Appendix 1, transfer/efficiency losses would also be reduced by 50 percent except boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$19,376,500
Operating Cost	11,636,300
Maintenance Cost	3,257,000
Offloading Cost	1,400,500
Transfer/Efficiency Cost	15,854,000
TOTAL COST (20 LAUNCHES/YEAR)	$51,524,300





SPECIFICATIONS

CAPACITY	-	13,250 GAL (GROSS) *
EMPTY WEIGHT	-	43,240 POUNDS
PRESSURE	-	INNER VESSEL - 45 POUNDS PER SQUARE INCH GAGE
	-	OUTER VESSEL - FULL VACUUM

FIGURE 4-1

13,000-GAL LH_2 MOBILE TANKER

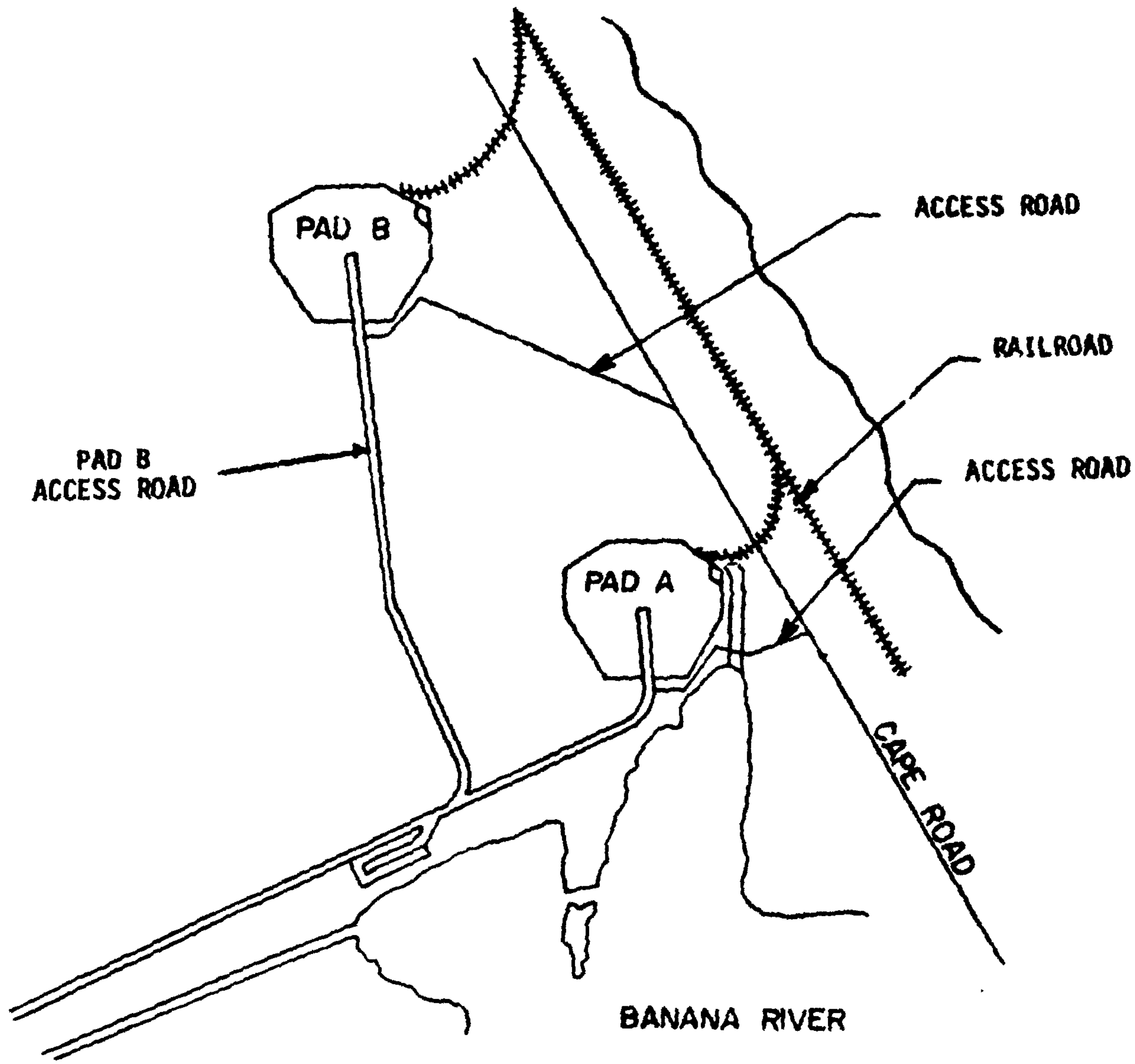


FIGURE 4-2

PROPOSED LH_2 BARGE/MOBILE TANKER SITE PLAN

APPENDIX 5

APPENDIX 5

OPTION 5 - BARGE/INVENTORY TANK COMBINATION

1.0 CONCEPT OF OPERATION

Option 5 is based on LH_2 delivery by Government-owned barge directly from the APCI facility in New Orleans to Pad A as in Option 1. Direct transfer of LH_2 from the barge to the storage sphere at Pad A would be accomplished by VJ pipeline. However, LH_2 for Pad B would be transferred to a 530,000-gal inventory tank located just outside the Pad A perimeter for later transfer to the storage sphere at Pad B at the most convenient time in the launch schedule. The 530,000-gal inventory tank would permit temporary storage of 500,000 gal of LH_2 for Pad B plus approximately 6-percent ullage. The use of the inventory tank would permit rapid offloading and release of the LH_2 barge (3-hour flow time) as opposed to the 18-hour offloading time required for transferring directly from the barge to mobile tankers.

To support 40 STS launches per year, 670,000 gal of LH_2 must be delivered into the storage spheres at Pads A and B each round trip. However, under this option, the increase in transfer/efficiency losses to approximately 87,000-gal resulting from triple pressurization and offloading of the barge, inventory tank, and mobile tankers requires that a barge with dewars of 850,000-gal gross capacity be used (Figure 5-1). A barge of this capacity would satisfy STS launch requirements and permit leaving up to 1,300 gal of LH_2 "heel" in each dewar after each delivery. The proposed 530,000-gal LH_2 inventory tank would be spherical in shape with double steel wall construction similar to the existing storage spheres at Pads A and B. The inner sphere would be approximately 54.5 feet in diameter and the outer sphere 63.5 feet in diameter. The annular space would be filled with perlite powder insulation evacuated below 50 microns. The inventory tank boiloff rate would be less than .5 percent per day.

The seven 13,000-gal LH_2 mobile tankers planned for use under this option include four presently in use by APCI at New Orleans and the three located at KSC as in Appendix 4. Under this option, all seven mobile tankers would be returned to KSC and would be operated in two serials for onloading from the inventory tank and offloading into the Pad B LH_2 sphere manifold. At 45-psig, the estimated onloading and offloading time would be approximately 1 hour each with 1-hour round trip travel time. Boiloff losses from the barge to Pad B would be negligible and would permit loading 12,400 gal of LH_2 into each tanker for the short haul to Pad B. The inventory tank would be equipped with sufficient 2-inch loading manifold bayonet connectors and parking spaces for simultaneous onloading of five mobile tankers. Except for the inventory tank, KSC barge channel and facilities required for this option would be identical to those described in Option 2. The proposed barge channel and inventory tank location for this option are shown in Figure 5-2.

The barge resupply cycle starts with each pad storage sphere containing 850,000-gal of LH_2 and the inventory tank containing 500,000-gal. When a launch from Pad A occurs, storage in Sphere A would be reduced to 350,000 gal. Nine days later, when a launch occurs from

Pad B, storage would be reduced to 350,000 gal in Sphere B. The day following the second launch, a barge would arrive and offload 500,000 gal by 8-inch VJ pipeline into Sphere A filling the sphere to 850,000 gal. The remaining portion of the barge shipment would be transferred to the inventory tank. Subsequently, LH_2 in the inventory tank would be transferred to 13,000-gal (nominal) mobile tankers and delivered into Sphere B. After every third barge delivery, each storage tank would contain 850,000 gal. The barge transportation model for this option is shown in Appendix 1, Figure 1-4. The barge and facility development schedules for this option are shown in Appendix 1, Figures 1-5 and 1-6.

2.0 INVESTMENT COST

The investment cost associated with this option includes procurement and construction of the proposed barge and associated docking facilities at Pad A, procurement of seven dedicated GSA tractors, and construction of the 500,000-gal LH_2 inventory tank and onloading facility. Estimated cost of the proposed barge, docking facilities, and GSA tractors is detailed in Appendix 4. For the 850,000-gal barge, a proportional cost increase of $104,000 is added under this option. The Chicago Bridge and Iron Company estimates the 1977 cost of a 530,000-gal (500,000 plus 6-percent ullage) LH_2 sphere at $3,150,000 including the cost of associated piping and mobile tanker onloading manifolds. As in Option 4, this option assumes the four NASA 13,000-gal LH_2 mobile tankers at APCI would be returned and that all seven mobile tankers would be available at no additional investment cost. Estimated total investment cost to the time at which KSC contracts would be awarded follows.

- <u>Equipment Investment</u>

	1976 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
One Barge (850,000-Gal Capacity)	$8,864,000	$12,432,000
Seven GSA Tractors		376,200
Total		$12,808,200

- <u>Cost Adjustment Factor (10 Percent)</u> $ 1,280,800

- <u>Facility Construction Cost</u>

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
Barge Facility	$3,050,000	$ 4,941,000
500,000-Gal Inventory Tank	3,150,000	5,103,000
Total		$10,044,000

- <u>Design Fee (6 Percent)</u> 602,690

- <u>APCI Dock Modifications (Appendix 1)</u> 50,000

<u>Total Investment Cost</u> $24,785,700

3.0 OPERATING COST

The operating cost of LH_2 delivery under this option includes the cost of barge transportation plus the cost of GSA tractor and mobile tanker delivery to Pad B. The estimated operating cost for the LH_2 barge and GSA tractor is detailed in Appendix 4. As the operating costs for GSA tractor/mobile tanker delivery from either the barge or inventory tank at Pad A to Pad B are assumed to be equal under this option, estimated operating costs follow.

●	Barge Operating Cost (Appendix 4)	$22,800,000
●	Mobile Tanker Operating Cost (Appendix 4)	$ 572,500
	Total Operating Cost	$23,272,500

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes barge corrosion control and refurbishment expenses combined with 13,000-gal mobile tanker maintenance functions, KSC Administration and Scheduling (A&S) costs, and inventory tank maintenance costs. The estimated cost of LH_2 barge maintenance is detailed in Appendix 7. The estimated cost of mobile tanker maintenance and A&S cost are detailed in Appendix 4. The maintenance cost associated with the LH_2 inventory tank is assumed to include repainting every 10 years plus periodic valve and instrumentation tests and adjustment. The 1977 price estimate for painting the LH_2 inventory tank is $25,000. Maintenance of valves and instrumentation is expected to require the presence of one individual for approximately 20 hours per week at the inventory tank site. Estimated combined maintenance cost for this option follows.

- <u>Inventory Tank Resurfacing (1987 Dollars)</u> $ 49,000

- <u>Inventory Tank Maintenance Cost</u>

YEAR	MAN-HOURS	COST/MAN-HOUR	COST/YEAR
1982	1,040	$19.51	$ 20,290
83	1,040	20.88	21,715
84	1,040	22.34	23,233
--	--	--	--
1991	1,040	35.87	37,305
	Inventory Tank Maintenance Cost		$ 280,000

- <u>Barge/Tanker Maintenance Cost (Appendix 4)</u> $3,257,000

<u>Total Maintenance Cost</u> $3,586,000

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and barge operating functions for offloading into both the Pad A LH_2 sphere and the inventory tank and for subsequent transfer from the inventory tank to the Pad B LH_2 sphere. Total barge offloading time for Pad A and the inventory tank should average approximately 3 hours. Transfer of LH_2 from the inventory tank to Pad B will be accomplished using the seven KSC 13,000-gal mobile tankers in serials of 4 and 3 tankers each. Total time for onloading the 13,000-gal mobile tankers from the inventory tank and offloading into the Pad B sphere should average approximately 18 hours, however, offloading teams are required in both areas simultaneously. Fire and Safety personnel are required in each area 1/2 hour prior to and following offloading operations. VO personnel are required in each area 1 hour prior to and following offloading operations to establish security, prepare the sites for operation, and shut down the sites following operations. Estimated cost factors and total offloading costs follow.

- Cost per Barge/Inventory Tank Offloading Operation ($19.51/Hour 1982 Dollars)

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST/TRANSFER
Safety	2	40	80	$ 1,560
Fire	8	40	320	6,243
VO	6	41	246	4,799
Barge Operators	3	3	9	176
Barge/Inventory Tank Transfer Cost				$12,778

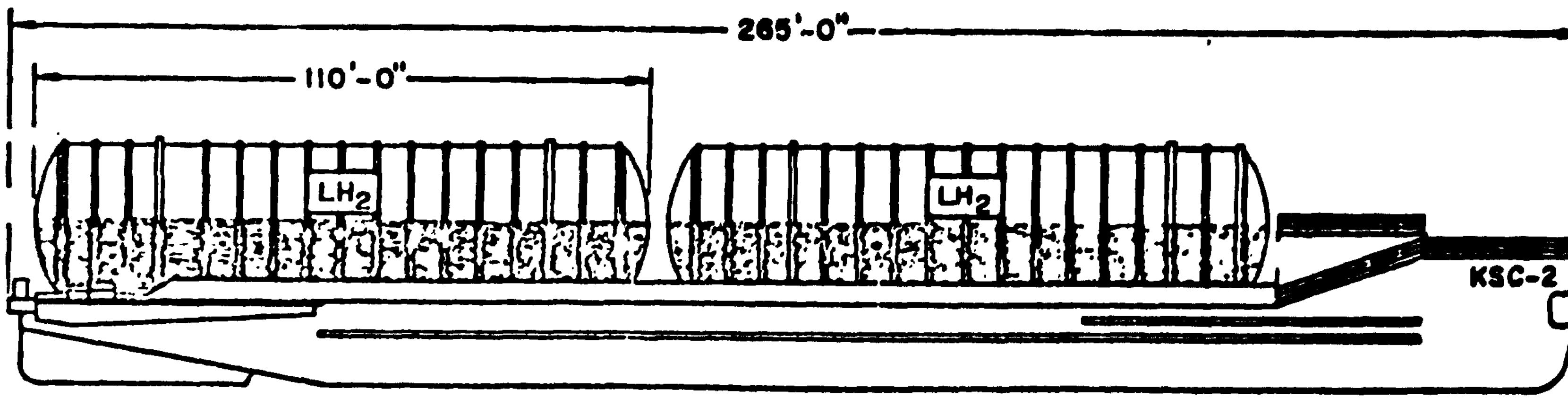
- Barge/Inventory Tank/Mobile Tanker Offloading Cost

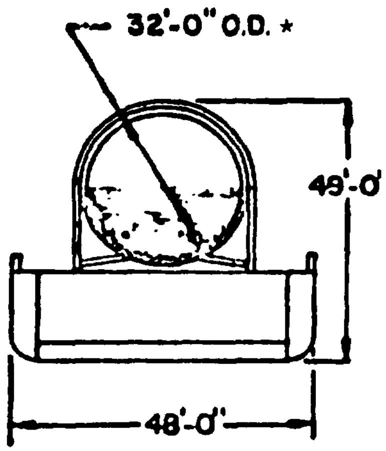
YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$12,778	10	$ 127,780
83	13,672	27	369,144
84	14,629	30	438,870
--	--	--	--
1991	23,490	30	704,700
Total Offloading Cost			$4,999,600

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is reduced dramatically. For example, at 20 launches per year, no reduction in investment or maintenance costs would be realized, however, a 50-percent reduction in operating and offloading costs could be achieved. As in Appendix 1, transfer/efficiency losses would also be reduced by 50 percent except barge and inventory tank boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$24,891,600
Operating Cost	11,636,200
Maintenance Cost	3,586,000
Offloading Cost	2,499,800
Transfer/Efficiency Cost	15,854,000
TOTAL COST (20 LAUNCHES/YEAR)	$58,467,600





SPECIFICATIONS

TANK INNER VESSEL	- ALUMINUM
TANK OUTER VESSEL	- CARBON STEEL
PRESSURE	- 50 POUNDS PER SQUARE INCH GAGE
CAPACITY	- 850,000 GAL GROSS
DRAFT	- 3.5' MINIMUM
	10.0' MAXIMUM

*O.D. = Outside Diameter

FIGURE 5-1
LH_2 BARGE

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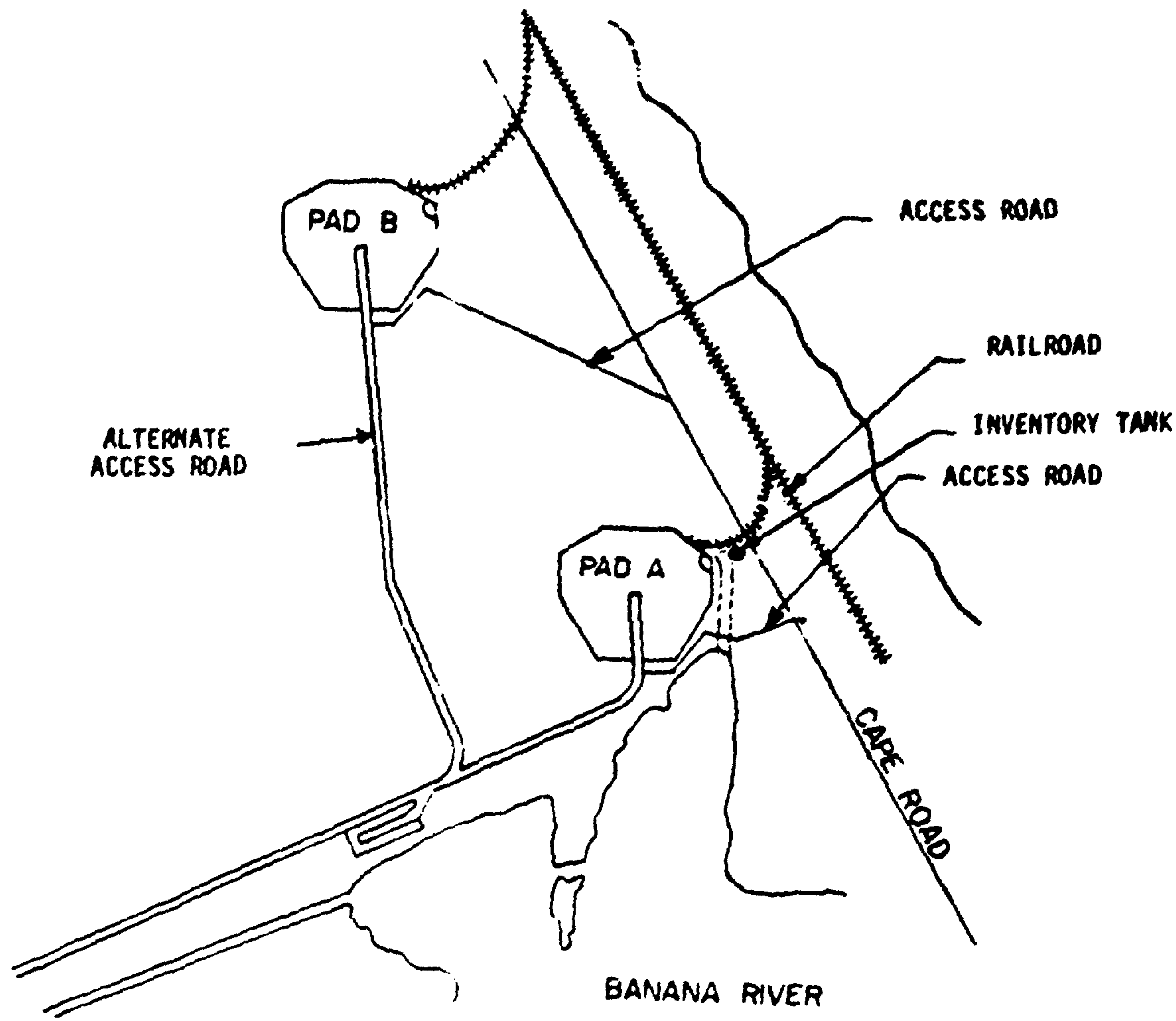


FIGURE 5-2

BARGE/INVENTORY TANK OPTION

APPENDIX 6

APPENDIX 6

OPTION 6 - 13,000-GAL MOBILE TANKER/COMMON CARRIER

1.0 CONCEPT OF OPERATION

Option 6 is based on the use of KSC-owned standard 13,000-gal mobile tankers to deliver LH_2 from APCI directly to the storage spheres at Pads A and B (Appendix 4, Figure 4-1). Delivery would be f.o.b. origin with transportation by common carrier tractors. To provide 500,000-gal of LH_2 per launch cycle and to compensate for 50,260 gal of transfer/efficiency losses, 48 mobile tanker loads would be required. Delivery of LH_2 into storage spheres at Pads A and B would be permitted only during days 1 through 7 of the launch cycle with no deliveries on the day preceding the (or the actual) launch date. To achieve this delivery rate, twenty mobile tankers operating in five sets of four tankers every 12 hours would be required. KSC LH_2 spheres have sufficient 2-inch manifold connections for simultaneous onloading of six mobile tankers. However, the use of lower pressures to minimize transfer losses at APCI requires 3 hours per 13,000-gal mobile tanker for onloading, and the filling of mobile tankers for other users further limits manifold time available.

Under this option, the four KSC mobile tankers presently in APCI possession would be returned to KSC after 31 March 1979. The seven existing KSC tankers, combined with the purchase of fourteen (one for maintenance spare) new mobile tankers would provide the minimum LH_2 fleet transport capability. Under this option, each 13,000-gal LH_2 mobile tanker would be loaded with 11,700 gal of LH_2 by APCI (assuming 6-percent ullage and a 6-percent water density safety fill factor). Depressurization, boiloff, and other transfer losses would amount to approximately 1,050 gal. Each mobile tanker should then deliver approximately 10,500 gal of LH_2 into the KSC storage spheres each round trip with 150 gal of "heel" retained in each tanker. To achieve the desired delivery rate, the tankers would operate on a 56-hour round trip delivery schedule with 12 hours for onload/offload at APCI and KSC and 16 hours enroute each direction. A round trip distance between KSC and APCI of 1,386 miles and the current APCI mileage rate using KSC mobile tankers f.o.b. APCI would be used to compute transportation costs. A proposed traffic model to support the 13,000-gal LH_2 mobile tanker option is shown in Figure 6-1. With this traffic model, approximately 1.5 days of maintenance time would be available during days 7 and 8 of each 9-day launch cycle. The equipment development schedule for this option is shown in Figure 6-2.

The proposed launch cycle would begin with the LH_2 storage spheres at Pads A and B each containing 850,000 gal of LH_2. When a launch from Pad A occurs, storage in Sphere A would be reduced to 350,000 gal. Beginning the day following launch and continuing for the next 6 days, four 13,000-gal LH_2 mobile tankers would arrive every 12 hours until the storage level in Sphere A is returned to 850,000 gal. The same procedure would be repeated for each launch from Pad B.

2.0 INVESTMENT COST

The estimated investment cost to support this option consists of the purchase of fourteen additional 13,000-gal LH_2 mobile tankers and expansion of the KSC LH_2 mobile tanker parking/maintenance facility. Although twenty-one mobile tankers are required, the seven existing KSC tankers are assumed to be available and serviceable in 1982. Cost estimates (1977 dollars) for additional 13,000-gal LH_2 mobile tankers were obtained from the following companies.

APCI	$296,500
LOX Equipment Company	$250,000
Russell Engineering Company	$225,000

Based upon this range of estimates, an average price of $257,000 was selected for this study. KSC Design Engineering (DE) estimates the cost for constructing a maintenance hardstand for LH_2 rechargers and for extending the existing LH_2 mobile tanker maintenance hardstand to accommodate up to 24 semitrailer units at $50,000. Projected estimates of investment cost to the time KSC contracts would be awarded follows.

- **Equipment Investment**

	1977 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
Fourteen 13,000-Gal LH_2 Mobile Tankers	\$3,598,000	\$4,716,200

- **Cost Adjustment Factor (10 Percent)** — \$ 471,600

- **Facility Construction Cost**

	1977 ENGINEERING ESTIMATE(E)	1981 BUDGET ESTIMATE (1.62E)
Mobile Tanker Maintenance Hardstand	\$50,000	\$ 81,000

- **Design Fee (6 Percent)** — \$ 4,800

Total Investment Cost \$5,273,600

3.0 OPERATING COST

The operating cost for LH_2 delivery under this option consists of common carrier mileage costs and APCI Terminal and Administration (T&A) costs for f.o.b. origin operations. Due to cancellation of the LH_2 common carrier contract by Matlack, no precise mileage cost presently exists. As a result, the 1982 mileage rate for GOCO mobile tanker delivery (Schedule B, Contract NAS8-31034) is used in this study as an estimated common carrier rate. APCI T&A cost for f.o.b. origin delivery was estimated at \$32,100 per year in 1976. This figure included salary, office space, and associated costs for APCI personnel performing administrative processing of KSC mobile tankers at the New Orleans facility. Operating cost factors and total operating cost for this option follow.

- Operating Cost Factors

Mileage Rate (NAS8-31034) $1.12/Mile (1982)

Mileage (Round Trip) 1,386

Tanker Loads Required . . . . 48/Launch Cycle

- Common Carrier Cost

YEAR	COST/ MILE	MILES	T&A COSTS	ROUND TRIPS	COST/YEAR F.O.B. ORIGIN
1982	$1.12	1,386	$48,173	624	$ 968,647
83	1.20	1,386	51,546	1,728	2,874,009
84	1.28	1,386	55,154	1,920	3,406,233
--	--	--	--	--	--
1991	2.06	1,386	88,565	1,920	5,481,907
		Common Carrier Cost			$38,836,000
APCI T&A Cost					665,500
		Total Operating Cost			$39,501,500

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes mobile tanker maintenance and refurbishment cost, brake and tire maintenance cost, and KSC Administration and Scheduling (A&S) cost. Based upon KSC maintenance records and current APCI refurbishing price quotations, the 1982 maintenance cost for each mobile tanker is estimated at $4,780 (Appendix 4). A&S costs for clerical salary and maintaining administrative records of mobile tanker operations at KSC by contractor personnel are estimated at $16,058 per year by 1982. No maintenance data for mobile tanker tire and brake costs under high mileage conditions presently exist, however, KSC Transportation Services has provided estimates of cost factors as indicated in the following estimated cost factors and total maintenance cost for this option.

- <u>Tire and Brake Cost for One Mobile Tanker</u>

  Tire Service Life . . . . 100,000 Miles

  Cost/Tire $150

  Tires/Tanker 8

  Tire Cost: (8) (150) = $0.012/Mile

  Brake Cost: $250 = $.025/Mile

  <u>Tire and Brake Cost = $.037/Mile</u>

- <u>Tire and Brake Cost (14 Mobile Tankers)</u>

YEAR	COST/MILE	MILES/TRIP	TRIPS	COST/YEAR
1982	$.052	1,386	624	$ 44,972
83	.055	1,386	1,728	131,725
84	.059	1,386	1,920	157,006
--	--	--	--	--
1991	.095	1,386	1,920	252,806
		Tire and Brake Cost		$1,788,200

- Mobile Tanker Maintenance Cost (14 Tankers In Service)*

YEAR	MAINTENANCE/ TANKER/YEAR	MAINTENANCE TOTAL	KSC A&S COST/YEAR	COST/YEAR
1982	$4,780	$66,920	$16,058	$ 82,978
83	5,115	71,610	17,182	88,792
84	5,473	76,622	18,385	95,007
--	--	--	--	--
1991	8,788	123,032	29,522	152,554
	Mobile Tanker Maintenance Cost			$1,1[illegible]
	Tire and Brake Cost			1,7[illegible]
	Maintenance Cost			$2,93[illegible]

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and mobile tanker operating functions.

Forty-eight 13,000-gal mobile tanker loads of LH_2 are required each launch cycle. For offloading purposes, these mobile tankers will arrive in twelve sets of four tankers each. The first set of four mobile tankers will arrive at KSC on the morning following an STS launch. The remaining eleven sets of mobile tankers will arrive every 12 hours until the LH_2 sphere is refilled to 850,000 gal. Twelve separate offloading operations every 12 hours for 6 consecutive days would be required. For offloading, four mobile tankers will be connected to the 2-inch intake manifolds at the LH_2 spheres at Pads A and B, pressurized to 45 psig, and offloaded in approximately 1 hour. Fire and Safety personnel are required in each area 1/2 hour prior to and following offloading operations. VO personnel are required in

*Maintenance for the 7 existing KSC 13,000-gal mobile tankers not shown.

each area 1 hour prior to and following offloading operations to establish security, prepare the sites for operation, and shut down the sites following operations. Estimated cost factors and total offloading costs follow.

- Offloading Cost Per Launch Cycle ($19.51/Hour 1982 Dollars)

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST/TRANSFER
Safety	1	2	24	$ 468
Fire	4	2	96	1,873
VO	3	3	108	2,107
Vehicle Drivers	4	2	96	1,873
	Offloading Cost per Launch Cycle			$6,321

- Mobile Tanker Offloading Cost

YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$ 6,321	13	$ 82,173
83	6,763	36	243,468
84	7,236	40	289,440
--	--	--	--
1991	11,620	40	464,800
		Total Offloading Cost	$3,295,000

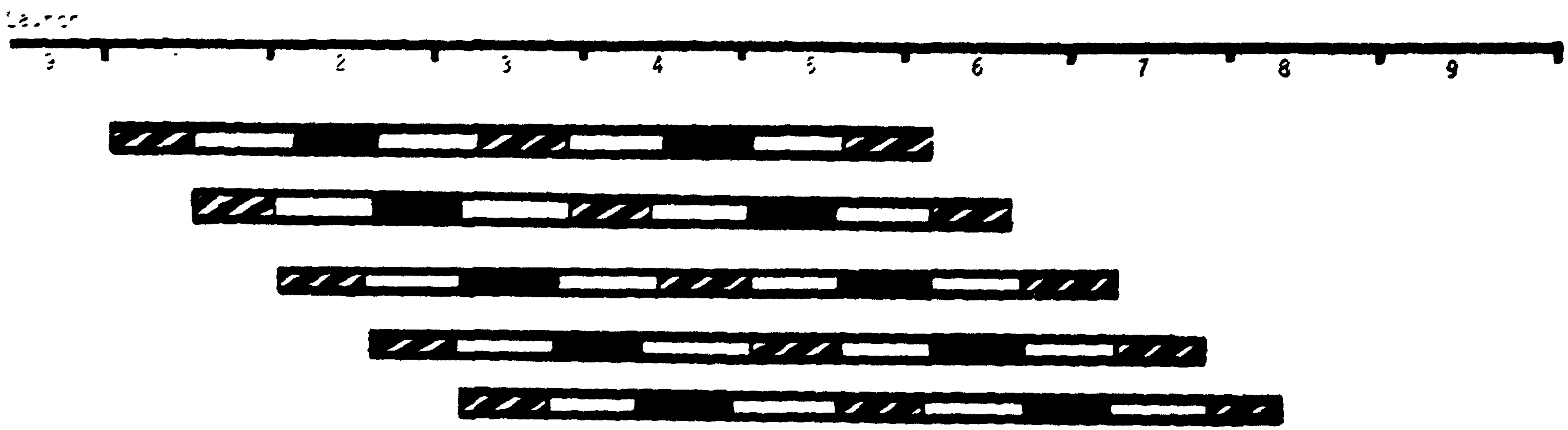
6.0 REDUCED LAUNCH RATE SENSITIVITY

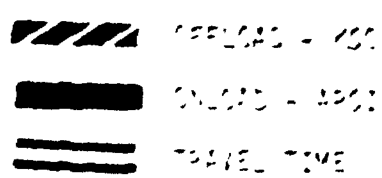
For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this optic is increased significantly. For example, at 20 launches per year, the purchase of only one additional

13,000-gal mobile tanker would be required. This tanker, combined with the seven existing KSC mobile tankers on a 56-hour round trip schedule would be more than adequate. The reduced mobile tanker fleet would permit a 60-percent reduction in maintenance and a 50-percent reduction in operating and offloading costs. Transfer/efficiency losses would also be reduced by 50 percent except boil-off losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$ 336,800
Operating Cost	19,755,800
Maintenance Cost	1,147,200
Offloading Cost	1,647,500
Transfer/Efficiency Cost	7,003,000
TOTAL COST (20 LAUNCHES/YEAR)	$29,890,300

9 DAY LAUNCH CYCLE





Four 13,000-gal mobile tankers load and depart APCI for KSC every 12 hours on a 56-hour round trip cycle. Forty-eight mobile tanker loads are required.

FIGURE 6-[illegible]

TRAFFIC MODEL

13,000-GAL MOBILE TANKER

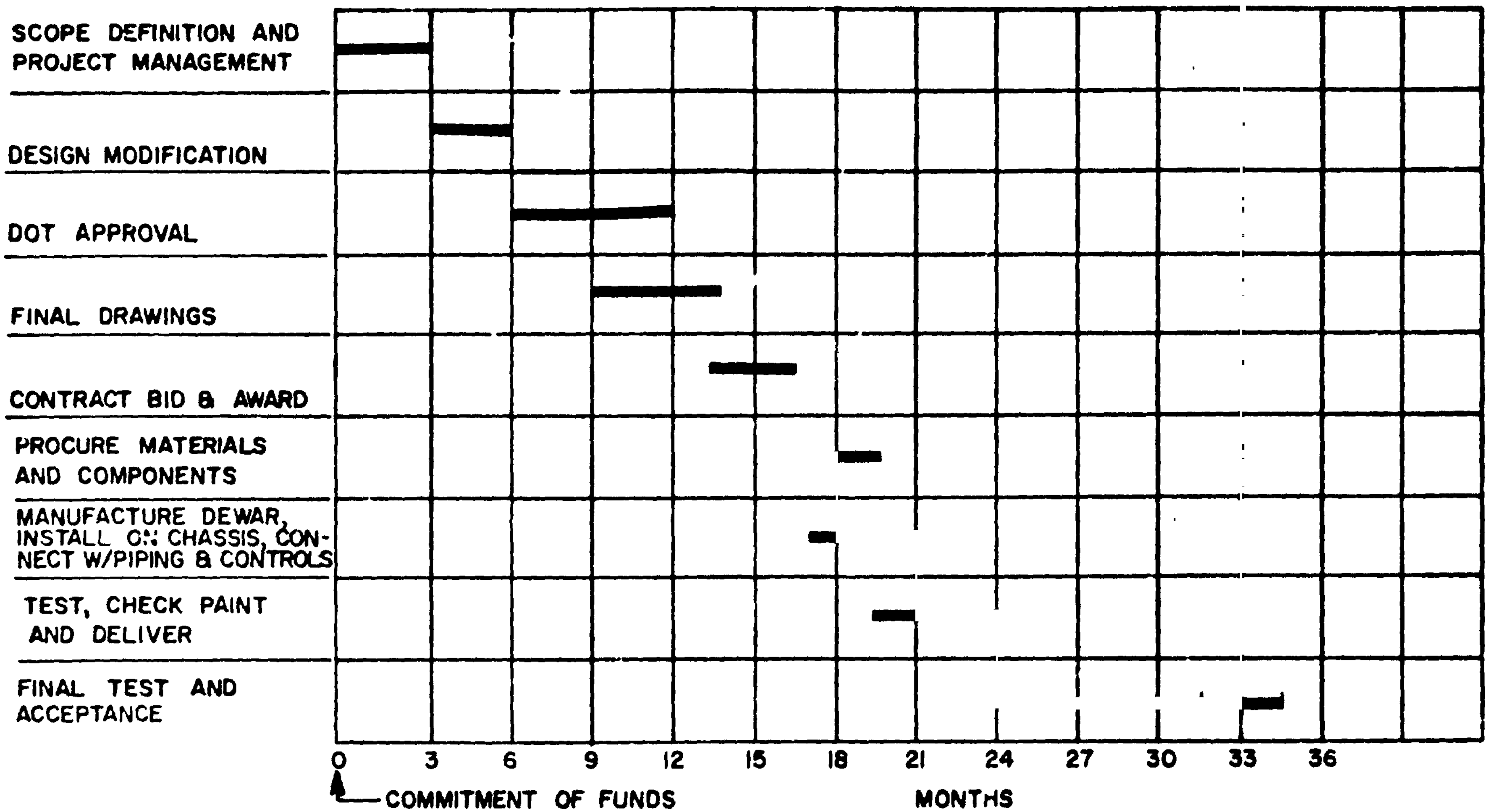


FIGURE 6-2

LH_2 13,000-GAL TANKER DEVELOPMENT SCHEDULE

APPENDIX 7

APPENDIX 7

OPTION 7 - 13,000-GAL MOBILE TANKER/GOCO TRACTORS

1.0 CONCEPT OF OPERATION

Option 7 is based on the use of KSC-owned 13,000-gal mobile tankers to transport LH_2 from APCI directly to the storage spheres at Pads A and B. This option is identical to Option 6 except that GSA GOCO trucks would be used instead of common carrier to transport the mobile tankers.

As the numbers and types of 13,000-gal mobile tankers and loads of LH_2 required are the same, the maintenance, offloading, and transfer losses are also identical to those of Appendix 6. However, the requirement for GSA-provided tractors and contractor-provided driver personnel presents special investment and operating cost considerations. The proposed traffic model to support this option is shown in Appendix 6, Figure 6-1. The 56-hour round trip schedule would permit 2 days of maintenance downtime during each 9-day launch cycle. The proposed LH_2 resupply cycle is identical to Option 6 and would be conducted only during days 1 through 7 of the launch cycle.

2.0 INVESTMENT COST

The estimated investment cost to support this option consists of the purchase of fourteen additional 13,000-gal LH_2 mobile tankers, expansion of the LH_2 mobile tanker parking/maintenance hardstand facility, and GSA procurement of twenty tandem-axle diesel tractors with sleepers. Although twenty-one mobile tankers are required (twenty operational, one spare), the seven existing KSC 13,000-gal mobile tankers are assumed to be available and serviceable in 1982 at no additional charge. The estimated investment cost for mobile tankers and the expanded parking/maintenance hardstand is detailed in Appendix 6. KSC Transportation Services estimates the cost of the tandem-axle diesel tractors with sleepers at $41,000 in 1977 dollars. With an expected useful life of 500,000 miles, two sets of diesel tractors would be required during the period 1982 through 1991. Maintenance of the diesel tractors would be performed by GSA in the existing KSC facility with no additional construction or facility requirements. The investment cost for this option at the time KSC contracts would be awarded follows.

- Equipment Investment

	1976 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
Fourteen Mobile Tankers (Appendix 6)	$3,598,000	$4,716,200
Twenty GSA Tractors With Sleepers ($53,742 each - 1981)	820,000	1,074,800
		$5,791,000

- Cost Adjustment Factor (10 Percent) 579,100

- Facility Construction Cost

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
Mobile Tanker Maintenance Hardstand (Appendix 6)	$ 50,000	$ 81,000

- Design Fee (6 Percent) 4,800

Total Investment Cost $6,455,900

3.0 OPERATING COST

The operating cost for this option consists of driver cost, GSA tractor cost, and APCI Terminal and Administration (T&A) cost. Driver cost is based on 40 hours of actual driving time for each mobile tanker round trip. Safety regulations require the driving time be divided between two individuals. The standard hourly wage used is $19.51 in 1982. The 1977 GSA charges for tandem-axle diesel tractors are presently $0.28 per mile plus a prorata share of a service charge of $180 per month. The $0.28 per mile includes fuel and cost of maintenance which is performed by GSA. The $180 monthly service charge is used by GSA to accumulate funds to purchase replacement vehicles when the existing tractors wear out. Due to the recent price increase of tandem-axle diesel tractors, the GSA service charge is expected to increase to $240 by 1982. The $0.28 mileage charge is based on a 1977 KSC diesel fuel cost of $0.40 per gal. As GSA trucks operating between KSC and APCI would require enroute refueling at $0.54 per gal for diesel fuel (price quotes from Standard, Gulf, and Shell Oil sources), the GSA mileage charge would be increased to approximately $0.32 per mile (1977 rate) for transporting LH_2 mobile tankers. The APCI T&A charges for this option are identical to those detailed in Appendix 6. Operating cost factors and the estimated costs for this option follow.

- Operating Cost Factors

Driver Cost . . . .$19.51/Hour (1982 Dollars)

Tractor Cost (Mileage). . . . . $0.45/Mile (1982 Dollars)

Tractor Cost (Service Charge) . . . . $4,040/Year (1982 Dollars)

Mileage (Round Trip) 1,386

Tanker Loads/Launch 48

Driver Hours/Round Trip 40

- GOCO Tractor Operating Cost

YEAR	ROUND TRIPS /YEAR	MILEAGE COST/YEAR	SERVICE CHARGE	COST/YEAR
1982	624	$ 389,188	$ 80,786	$ 469,974
83	1,728	1,149,603	86,442	1,236,045
84	1,920	1,383,782	92,493	1,476,275
--	--	--	--	--
1991	1,920	2,208,729	148,523	2,357,252
GOCO Tractor Operating Cost		$15,616,112	$977,379	$16,593,500

- Driver Operating Cost

YEAR	LAUNCHES	COST/MAN-HOUR	COST/YEAR
1982	13	$19.51	$ 486,970
83	36	20.88	1,443,226
84	40	22.34	1,715,712
--	--	--	--
1991	40	[illegible].87	2,754,815
		Driver Operating Cost	$19,530,500
APCI T&A Cost (Appendix 6)			665,587
		Total Operating Cost	$36,789,600

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes mobile tanker maintenance and refurbishment cost, trailer brake and tire maintenance cost, and KSC Administration and Scheduling (A&S) costs. Each of these costs is detailed in Appendix 6. Maintenance cost for GSA trucks is included in the $0.32 mile operating cost. Estimated maintenance cost for this option follows.

• Mobile Tanker Maintenance and A&S Cost (Appendix 6)	$1,146,500
• Tire and Brake Cost (Appendix 6)	1,788,200
Total Maintenance Cost	$2,934,700

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations(VO), and mobile tanker operating functions as in Option 6. The proposed offloading concept, personnel requirements, cost factors, and offloading costs are detailed in Appendix 6.

• Mobile Tanker Offloading Cost

YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$6,321	13	$ 82,173
83	6,763	36	243,468
84	7,236	40	289,440
--	--	--	--
1991	11,620	40	464,800
		Total Offloading Cost	$3,295,000

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is increased significantly. For example, at 20 launches per year, investment costs could be reduced to the purchase of one additional 13,000-gal mobile tanker to augment the existing KSC fleet of seven tankers and the purchase of eight GSA tandem-axle diesel tractors. Maintenance costs could be reduced by 60 percent by reducing the mobile tanker fleet from twenty-one to eight units and a 50-percent reduction could be achieved in operating and offloading costs. Transfer/efficiency losses would also be reduced by 50 percent except boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$ 766,700
Operating Cost	18,394,800
Maintenance Cost	1,147,200
Offloading Cost	1,647,500
Transfer/Efficiency Cost	7,003,000
TOTAL COST (20 LAUNCHES/YEAR)	$28,959,200

APPENDIX 8

APPENDIX 8

OPTION 8 - 19,700-GAL MOBILE TANKER/COMMON CARRIER

1.0 CONCEPT OF OPERATION

Option 8 is based on the use of KSC-owned 19,700-gal mobile tankers to deliver LH_2 from APCI directly to the storage spheres at Pads A and B (Figure 8-1). Delivery would be f.o.b. origin with transportation provided by common carrier tractors.

The 19,700-gal volume represents the maximum capacity possible in terms of LH_2 mobile tanker size and weight restrictions imposed by DOT and State highway regulations without requiring special overize or overweight permits and authorizations. The proposed 19,700-gal mobile tanker would require rectangular construction with a super-insulated stainless steel inner liner, carbon steel outer vessel, 0.5-percent-per-day maximum evaporation rate, and 60-psig operating pressure.

To provide 500,000 gal of LH_2 per launch cycle and to compensate for 49,400-gal transfer/efficiency losses, 32 mobile tanker loads would be required. Delivery of LH_2 into storage spheres at Pads A and B would be permitted only on days 1 through 7 of the launch cycle with no deliveries on the day preceding the (or the actual) launch date. To achieve this delivery rate, twelve mobile tankers operating in three sets of four tankers every 12 hours with a 20-hour gap between waves would be required. KSC LH_2 spheres have sufficient 2-inch manifold connections for simultaneous offloading of up to five mobile tankers and APCI has sufficient 2-inch manifold connections for simultaneous onloading of up to six mobile tankers.

However, the use of lower pressures to minimize transfer losses at APCI requires 3 hours per each 19,700-gal mobile tanker for onloading.

Under this option, KSC would purchase thirteen new 19,700-gal mobile tankers (twelve operational - one maintenance spare) which would provide more than adequate LH_2 fleet transport capability. Under this option, each 19,700-gal LH_2 mobile tanker would be loaded with 17,600 gal of LH_2 by APCI (assuming 6-percent ullage and a 6-percent water density safety fill factor). Depressurization, boiloff, and other transfer losses would amount to approximately 1,500 gal. Each mobile tanker should then deliver approximately 16,000 gal of LH_2 into the KSC storage spheres each round trip with 100 gal of "heel" retained in each tanker. To achieve the desired delivery rate the tankers would operate on a 56-hour round trip delivery schedule with 12 hours for onload/offload at APCI and KSC and 16 hours enroute each direction. A round trip distance between KSC and APCI of 1,386 miles and the current APCI mileage rate using KSC mobile tankers f.o.b. APCI would be used to compute transportation costs. A proposed traffic model to support the 19,700-gal LH_2 mobile tanker option is shown in Figure 8-2. With this traffic model, approximately 1.5 days of maintenance time would be available during days 7 and 8 of each 9-day launch cycle. The equipment development schedule for this option is shown in Figure 8-3.

The proposed launch cycle would begin with the LH_2 storage spheres at Pads A and B each containing 850,000 gal of LH_2. When a launch from Pad A occurs, storage in Sphere A would be reduced to 350,000 gal. Beginning the day following launch and as indicated in the traffic diagram, eight waves of four 19,700-gal LH_2 mobile tankers would arrive until the storage level in Sphere A is returned to 850,000 gal. The same procedure would be repeated for each launch from Pad B.

2.0 INVESTMENT COST

The estimated investment cost to support this option consists of the purchase of thirteen 19,700-gal LH_2 mobile tankers and expansion of the KSC LH_2 mobile tanker parking maintenance facility. Twelve mobile tankers are required for operations with one required as a maintenance spare. Cost estimates for the 19,700-gal LH_2 mobile tankers were obtained from the following companies (1977 dollars).

LOX Equipment Company $475,000

Russell Engineering Company $500,000

Based upon these estimates, a price of $500,000 was selected for this study. KSC Design Engineering (DE) estimates the cost for constructing a concrete maintenance pad for LH_2 rechargers and for extending the existing LH_2 mobile tanker parking hardstand to accommodate up to 15 semitrailer units at $35,000. Projected estimates of investment cost to the time KSC contracts would be awarded follows.

- <u>Equipment Investment</u>

	1977 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
Thirteen 19,700-Gal LH_2 Mobile Tankers	\$6,500,000	\$8,520,000

- <u>Cost Adjustment Factor (10 Percent)</u> \$ 852,000

- <u>Facility Construction Cost</u>

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
Mobile Tanker Maintenance Hardstand	\$ 35,000	\$ 56,700
Design Fee (6 Percent)		3,400
Total Investment Cost		\$9,432,100

3.0 OPERATING COST

The operating cost for LH_2 delivery under this option consists of common carrier mileage costs and APCI Terminal and Administration (T&A) costs for f.o.b. origin operations as in Option 6. Although the 19,700-gal mobile tanker is heavier than the standard 13,000-gal tanker, the 1982 mileage rate for GOCO mobile tanker delivery (Schedule B, Contract NAS8-31034) is also used in this option for common carrier delivery. Mileage rates and APCI T&A costs for f.o.b. origin delivery under this option are detailed in Appendix 6. Operating cost factors and total operating cost for this option follow.

- <u>Operating Cost Factors</u>

Mileage Rate (NAS8-31034) \$1.12/Mile (1982)

Mileage (Round Trip) 1,386

Tanker Loads Required . . . . 32/Launch Cycle

- Common Carrier Cost

YEAR	COST/MILE	MILES	ROUND TRIPS	COST/YEAR
1982	$1.12	1,386	416	$ 645,765
83	1.20	1,386	1,152	1,916,006
84	1.28	1,386	1,280	2,270,822
--	--	--	--	--
1991	2.06	1,386	1,280	3,654,604
		Common Carrier Cost		$25,890,919

- APCI T&A Cost (Appendix 6) 665,587

Total Operating Cost $26,556,506

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes mobile tanker maintenance and refurbishment cost, brake and tire maintenance cost, and KSC Administration and Scheduling (A&S) cost. For purposes of this study, each of these costs are assumed to be identical for both the 19,700-gal and the standard 13,000-gal LH_2 mobile tankers. The maintenance, brake and tire, and A&S cost factors are detailed in Appendix 6. Estimated maintenance costs based upon these factors and the thirteen mobile tankers required for this option follow.

- Mobile Tanker Maintenance Cost (13 Tankers In Service)

YEAR	MAINTENANCE/ YEAR/TANKER	MAINTENANCE TOTAL	KSC A&S COST/YEAR	COST/YEAR
1982	$4,780	$ 62,140	$16.058	$ 78,198
83	5,115	66,495	17,182	83,677
84	5,473	71,149	18,385	89,534
--	--	--	--	--
1991	8,788	114,244	29,522	143,766
		Mobile Tanker Maintenance Cost		$1,080,400

- Brake and Tire Cost

YEAR	COST/MILE	MILES/TRIP	TRIPS	COST/YEAR
1982	$.045	1,386	416	$ 25,945
83	.048	1,386	1,152	76,640
84	.052	1,386	1,280	92,252
--	--	--	--	--
1991	.083	1,386	1,280	148,136
		Brake and Tire Cost		$1,049,000
		Total Maintenance Cost		$2,129,400

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and mobile tanker operator functions. Thirty-two 19,700-gal mobile tanker loads of LH_2 are required each launch cycle. For offloading purposes, these mobile tankers will arrive in eight sets of four tankers each. The first set of four tankers will arrive at KSC on the morning following an STS launch. The remaining seven sets of mobile tankers will arrive every 12 hours except for a 20 hour break following the third and sixth sets until the LH_2 sphere is refilled to 850,000 gal. Eight separate offloading operations are required. For offloading, four mobile tankers will be connected to the 2-inch intake manifolds at the LH_2 spheres at Pads A and B, pressurized to 45 psig, and offloaded in approximately 2 hours. Fire and Safety personnel are required in each area 1/2 hour prior to and following offloading operations. VO personnel are required in each area 1 hour prior to and following offloading operations to establish security, prepare the sites for operation, and shut down the sites following operations. Estimated cost factors and total offloading costs follow.

- Offloading Cost per Launch Cycle ($19.51/Hour 1982 Dollars)

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST/TRANSFER
Safety	1	3	24	$ 468
Fire	4	3	96	1,873
VO	3	4	96	1,873
Vehicle Drivers	4	4	128	2,497
	Cost per Launch Cycle			$6,711

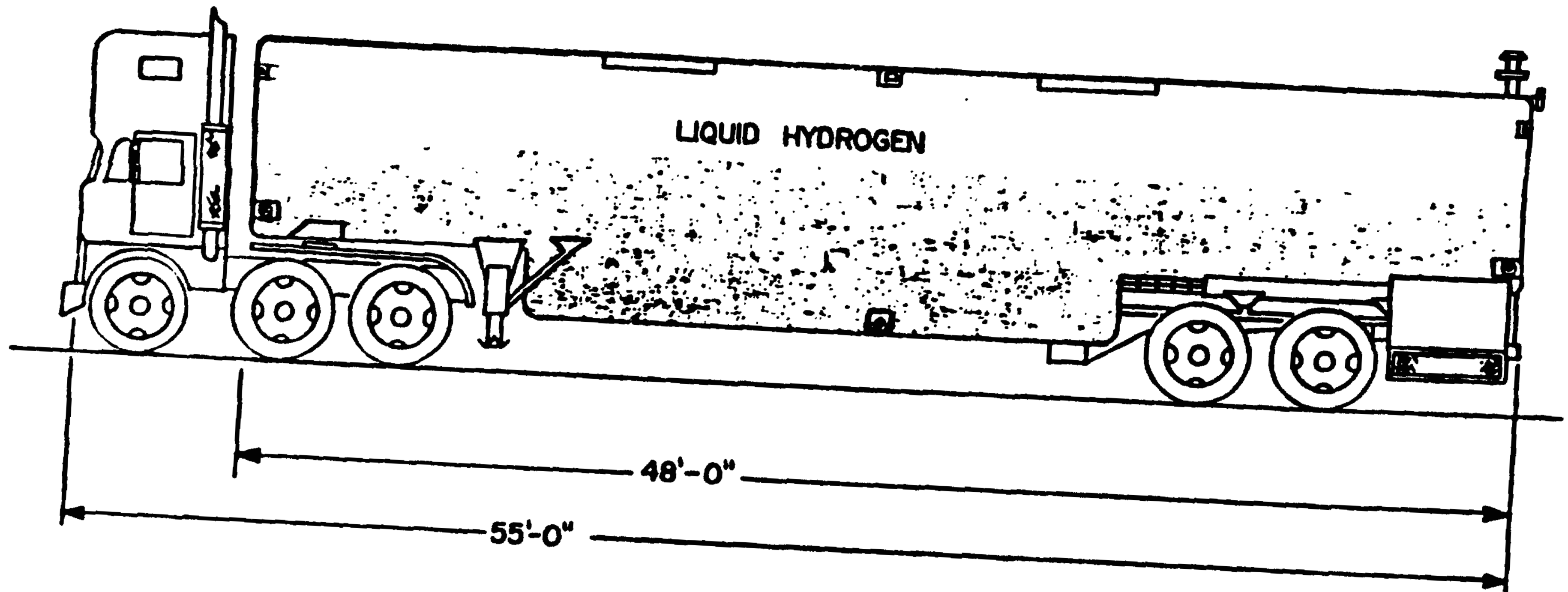
- Mobile Tanker Offloading Cost

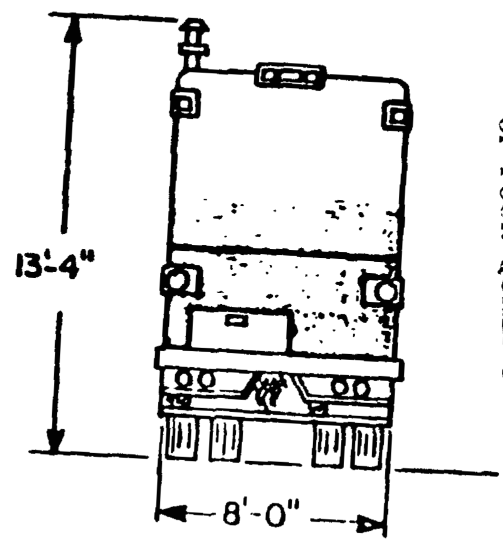
YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$6,711	13	$ 87,243
83	7,180	36	258,480
84	7,683	40	307,320
--	--	--	--
1991	12,336	40	493,440
		Total Offloading Cost	$3,498,300

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is increased significantly. For example, at 20 launches per year, investment and maintenance costs could be reduced by 54 percent as only six new mobile tankers would be required. In addition, a 50-percent reduction in operating and offloading costs could be achieved. Transfer/efficiency losses would also be reduced by 50 percent except boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$ 5,046,500
Operating Cost	13,278,700
Maintenance Cost	982,800
Offloading Cost	1,799,200
Transfer/Efficiency Cost	6,881,000
TOTAL COST (20 LAUNCHES/YEAR)	$27,988,200



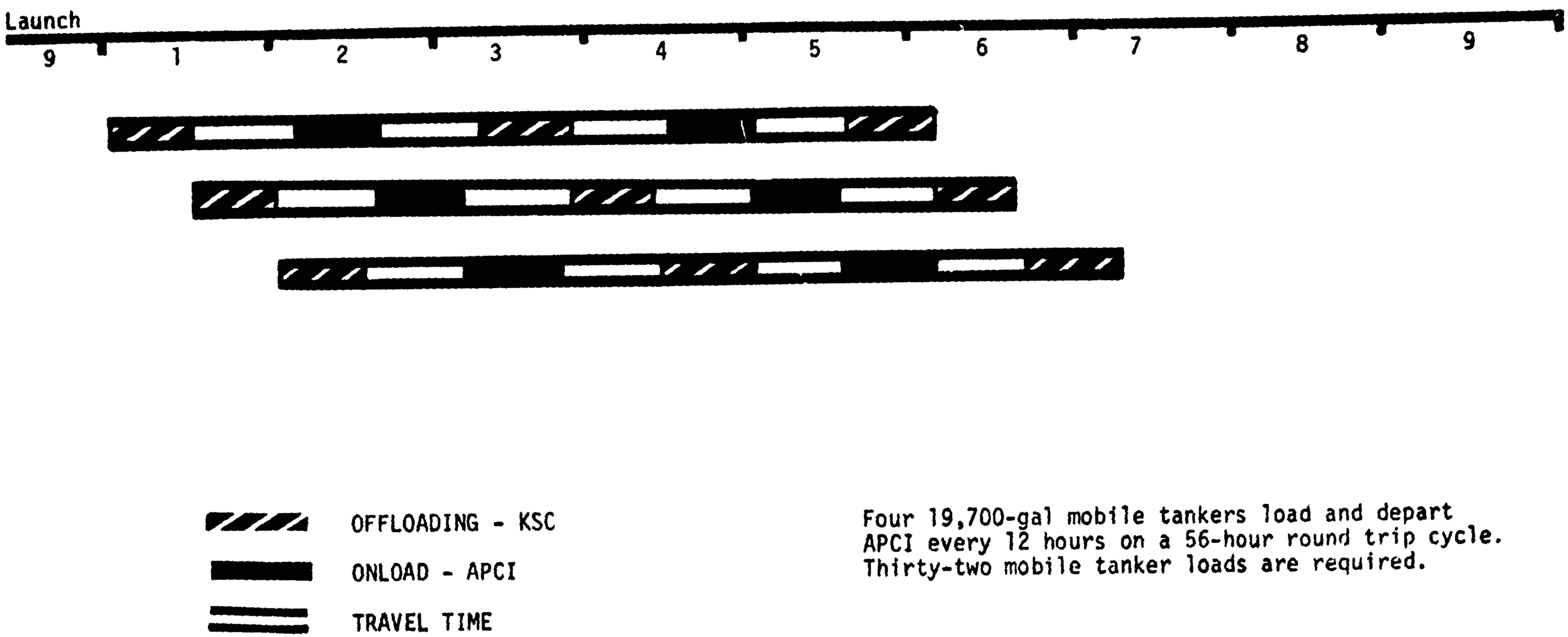


SPECIFICATIONS

CAPACITY	-	19,700-GAL GROSS
EMPTY WEIGHT	-	60,000 POUNDS
PRESSURE	-	INNER VESEEL - 20 POUNDS PER SQUARE INCH GAGE
	-	OUTER VESSEL - FULL VACUUM

FIGURE 8-1
19,700-GAL LH_2 MOBILE TANKER

9 DAY LAUNCH CYCLE



Four 19,700-gal mobile tankers load and depart APCI every 12 hours on a 56-hour round trip cycle. Thirty-two mobile tanker loads are required.

FIGURE 8-2

TRAFFIC MODEL

19,700-GAL MOBILE TANKER

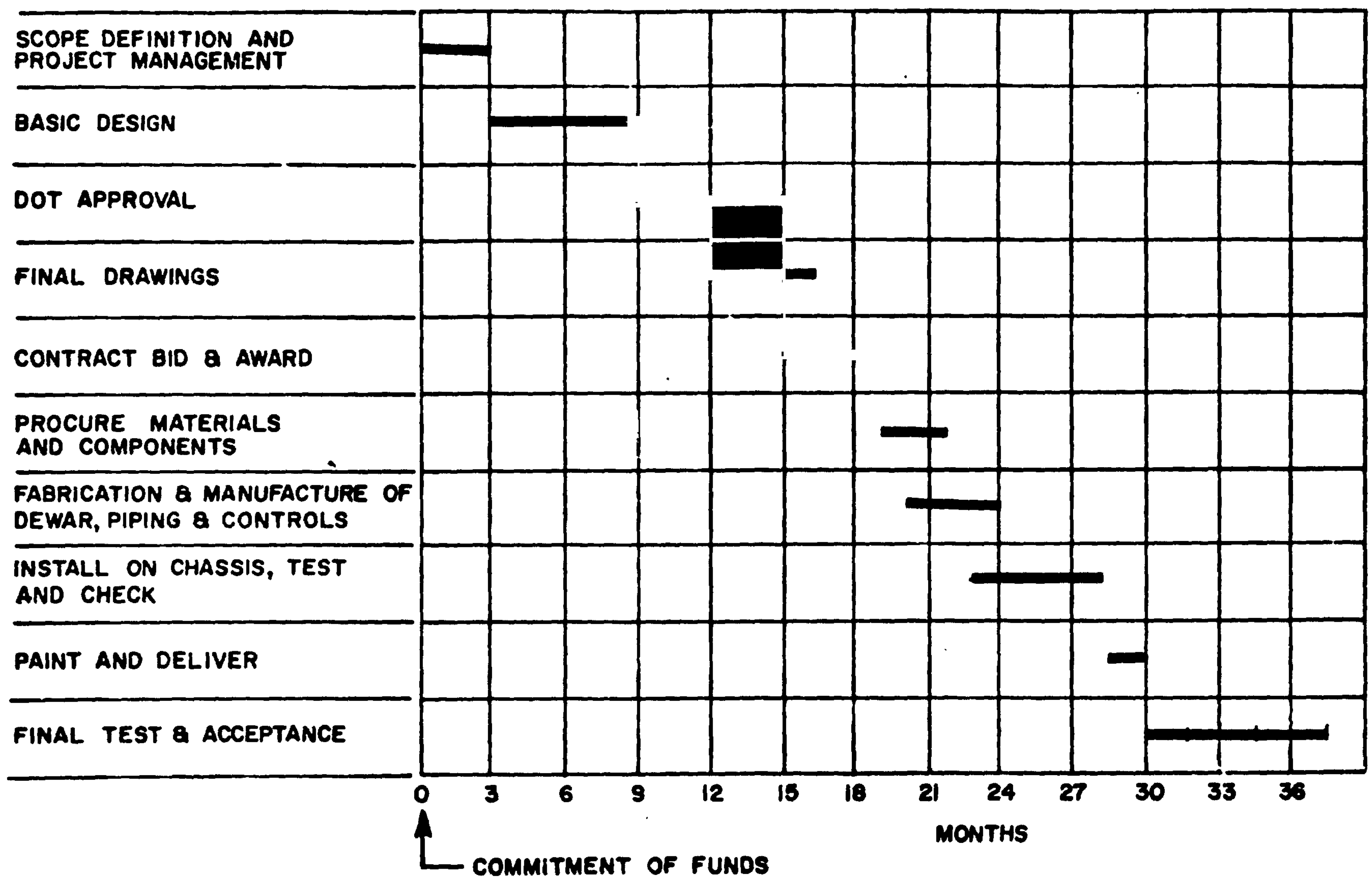


FIGURE 8-3

LH_2 19,700-GAL TANKER DEVELOPMENT SCHEDULE

APPENDIX 9

APPENDIX 9

OPTION 9 - 19,700-GAL MOBILE TANKER/GOCO TRACTORS

1.0 CONCEPT OF OPERATION

Option 9 is based on the use of KSC-owned 19,700-gal mobile tankers to transport LH_2 from APCI directly to the storage spheres at Pads A and B. This option is identical to Option 8 except that GSA GOCO tractors would be used instead of common carrier to transport the mobile tankers.

As the number and types of 19,700-gal mobile tankers and loads of LH_2 required are the same; the maintenance, offloading, and transfer losses are also identical to those of Appendix 8. However, the requirement for GSA-provided tractors and contractor-provided driver personnel present special investment and operating cost considerations. The proposed traffic model to support this option is shown in Appendix 8, Figure 8-2. The 56-hour schedule would permit 2-days maintenance downtime during each 9-day launch cycle. The proposed LH_2 resupply cycle is identical to Option 8 and would be conducted only during days 1 through 7 of the launch cycle.

2.0 INVESTMENT COST

The estimated investment cost to support this option consists of the purchase of thirteen new 19,700-gal LH_2 mobile tankers, expansion of the LH_2 mobile tanker parking/maintenance hardstand, and GSA procurement of twelve tandem-axle diesel tractors with sleepers. The cost of 19,700-gal LH_2 tankers and the expanded mobile tanker maintenance hardstand is detailed in Appendix 8. The cost of the of the tandem-axle diesel tractors with sleepers is detailed in Appendix 7. Maintenance of the diesel tractors would be performed by GSA in the existing KSC facility with no requirements for additional construction or facilities. The investment cost for this option at the time KSC contracts would be awarded follows.

- Equipment Investment

	1977 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
Thirteen Mobile Tankers (Appendix 8)	$6,500,000	$8,520,000
Twelve GSA Tractors With Sleepers ($53,742 each - 1981)	492,000	644,900
• Cost Adjustment Factor (10 Percent)		916,500

- Facility Construction Cost

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
Mobile Tanker Maintenance Hardstand (Appendix 6)	$ 35,000	$ 56,700
• Design Fee (6 Percent)		$ 3,400
Total Investment Cost		$10,141,500

3.0 OPERATING COST

The operating cost for this option consists of driver cost, GSA tractor cost, and APCI Terminal and Administration (T&A) cost. Each of these costs is detailed in Appendix 7. Although the 19,700-gal LH_2 mobile tanker is heavier, GSA costs for tractor operations are assumed to be equivalent to those for standard 13,000-gal mobile tankers. The only significant difference is that only 32 round trips per launch are required with this option compared with 48 round trips required with Option 7. Operating cost factors and estimated cost for this option follow.

- Operating Cost Factors (Appendix 7)

  Driver Cost . . . . $19.51/Hour (1982 Dollars)

  Tractor Cost (Mileage . . . . $0.45/Mile (1982 Dollars)

  Tractor Cost (Service Charge) . . . $4,040/Year (1982 Dollars)

  Mileage (Round Trip) 1,386

  Tanker Loads/Launch 32

  Driver Hours/Round Trip 40

- GOCO Tractor Operating Cost

YEAR	ROUND TRIPS/ YEAR	MILEAGE COST/YEAR	SERVICE CHARGE /YEAR	COST/YEAR
1982	416	$ 259,459	$ 48,480	$ 307,939
83	1 [illegible]2	768,797	51,873	820,670
84	1,280	914,014	55,504	969,518
--	--	--	--	--
1991	1,280	1,467,706	89,128	1,556,834
		Tractor Operating Cost		$11,075,673

- Driver Operating Cost

YEAR	LAUNCHES	COST/MAN-HOUR	COST/YEAR
1982	13	$19.51	$ 324,646
83	36	20.88	961,952
84	40	22.34	1,143,654
--	--	--	--
1991	40	35.87	1,831,936
		Driver Operating Cost	$13,019,000

- APCI T&A Cost (Appendix 6) — 665,500

Total Operating Cost — $24,760,200

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes mobile tanker maintenance and refurbishment cost, brake and tire maintenance cost, and KSC Administration and Scheduling (A&S) costs. Each of these costs is detailed in Appendix 8. Maintenance costs for GSA trucks are included in the $0.32 mile operating cost. Estimated maintenance cost for this option follows.

- Mobile Tanker Maintenance and A&S Cost (Appendix 8) — $1,080,400
- Brake and Tire Cost (Appendix 8) — $1,049,000

Total Maintenance Cost — $2,129,400

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and mobile tanker operator functions as in Option

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8. The proposed offloading concept, personnel requirements, cost factors, and offloading costs are detailed in Appendix 8.

- Mobile Tanker Offloading Cost $3,498,300

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is increased significantly. For example, at 20 launches per year, investment costs could be reduced to the purchase of six 19,700-gal mobile tankers and eight GSA tandem-axle diesel tractors. Maintenance costs could be reduced by 55 percent by reducing the mobile tanker fleet and a 50-percent reduction could be achieved in operating and offloading costs. Transfer/efficiency losses would also be reduced by 50 percent except boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$ 4,680,200
Operating Cost	12,380,200
Maintenance Cost	982,800
Offloading Cost	1,749,200
Transfer/Efficiency Cost	6,881,000
TOTAL COST (20 LAUNCHES/YEAR)	$26,673,400

APPENDIX 10

APPENDIX 10

OPTION 10 - APCI 13,000-GAL MOBILE TANKERS

(F.O.B. KSC PADS A & B)

1.0 CONCEPT OF OPERATION

Option 10 is based on the use of APCI tractors and APCI 13,000-gal mobile tankers (Figure 10-1) to transport LH_2 from New Orleans directly to the storage spheres at Pads A and B. Method of delivery would be f.o.b. KSC. Should APCI use existing KSC-owned 13,000-gal mobile tankers, NASA will be reimbursed at a specified contract mileage rate for this use. The basic LH_2 supply contract (NAS8-31034) provides for paying APCI at a fixed mileage rate through mid-1982. This price includes amortization of the APCI LH_2 mobile tanker fleet. For APCI delivery f.o.b. KSC after that date, negotiation of a new contract price by MSFC would be required. The existing contract includes the following negotiated transportation rates.

CONTRACT YEAR*	MILEAGE RATE/MILE
July 1977 - June 1978	$1.41
July 1978 - June 1979	1.47
July 1979 - June 1980	1.53
July 1980 - June 1981	1.60
July 1981 - June 1982	1.67

* A rebate of $0.55/mile for the use of KSC-owned 13,000-gal LH_2 tankers is currently in effect for the four mobile tankers being used by APCI. It is assumed that the same rebate would apply to additional KSC mobile tankers provided to APCI.

To provide 505,000 gal of LH_2 per launch and to compensate for approximately 50,000 gal in transfer/efficiency losses, approximately 560,000 gal of LH_2 would be loaded into APCI mobile tankers at APCI. Delivery of LH_2 directly into storage spheres at Pads A and B would be accomplished during days 1 through 7 of the launch cycle with no deliveries on the day preceeding the (or the actual) launch date. To achieve this delivery rate, 48 standard 13,000-gal mobile tanker loads of LH_2 would be required. Four tankers would be filled and would depart APCI fill manifolds every 12 hours with 16 hours of travel time between APCI and KSC and a 12-hour maximum turnaround delay at KSC. The round trip distance between KSC and APCI of 1,386 miles and the current APCI contract mileage rate would be used to compute transportation costs. Any delay longer than 2 hours would require KSC to pay demurrage at the rate of $6.00 for each 15 minutes or fraction thereof.

The proposed launch cycle would begin with each pad storage sphere containing 850,000 gal of LH_2. When a launch occurs from Pad A, storage in Sphere A would be reduced to 350,000 gal. Beginning the day following launch and continuing for the next 6 days, four 13,000-gal LH_2 mobile tankers would arrive every 12 hours (except on days 3 and 6 when a 12-hour gap occurs) until the storage level in Sphere A is returned to 850,000 gal. The same procedure would be repeated for each launch from Pad B.

2.0 INVESTMENT COST

Under this option, APCI mobile tankers and tractors are used to resupply LH_2 requirements at KSC. For this reason, no KSC investment in facilities or equipment is required. Contract mileage rates (operating costs) were designed to permit APCI to amortize the fleet of 13,000-gal LH_2 tankers which would be required to support this option.

3.0 OPERATING COST

Operating cost associated with this option includes reimbursement of APCI in accordance with the NAS8-31034 LH_2 contract for LH_2 delivered f.o.b. KSC. Estimated cost factors and the operating cost for the period 1982 through 1991 follow.

- Operating Cost Factors*

  APCI Charge . . . . $1.67/Mile (1982 Dollars)

  Mileage . . . . 1,386 (Round Trip)

  Round Trips 48/Launch

* It should be noted that, with the $0.55 per mile amortization cost removed, the operating cost of this option would be the equivalent of common carrier delivery using KSC-owned mobile tankers (Option 6).

- APCI Cost

YEAR	COST/MILE	MILES	ROUND TRIPS	COST/YEAR F.O.B. DESTINATION
1982	$1.67	1,386	624	$ 1,444,322
83	1.79	1,386	1,728	4,287,064
84	1.91	1,386	1,920	5,082,739
85	2.05	1,386	1,920	5,438,530
86	2.19	1,386	1,920	5,819,228
87	2.34	1,386	1,920	6,226,574
88	2.51	1,386	1,920	6,662,434
89	2.68	1,386	1,920	7,128,804
90	2.87	1,386	1,920	7,627,820
1991	3.07	1,386	1,920	8,161,768
	Total Operating Cost			$57,879,300

NOTE: If the seven existing KSC 13,000-gal mobile tankers are used by APCI to deliver LH_2 to Pads A and B, a credit of $0.55/ mile would be accrued. Assuming the standard three round trips per mobile tanker per launch (21 total mobile tanker round trips), the APCI operating cost of this option would be reduced as follows.

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YEAR	APCI COST F.O.B. DESTINATION	KSC TANKER REFUND	NET APCI OPERATING COST
1982	$ 1,444,322	$ 208,107	$ 1,236,215
83	4,287,064	576,298	3,710,766
84	5,082,739	640,332	4,442,407
85	5,438,530	640,332	4,798,198
86	5,819,228	640,332	5,178,896
87	6,226,574	640,332	5,586,242
88	6,662,434	640,332	6,022,102
89	7,128,804	640,332	6,488,472
90	7,627,820	640,332	6,987,488
1991	8,161,768	640,332	7,521,436
	$57,879,283	$5,907,061*	$51,972,222

4.0 MAINTENANCE COST

No KSC equipment or facilities investments were considered under this option. For this reason, no KSC maintenance costs are assumed.

5.0 OFFLOADING COST

Offloading cost for this option includes manning for Safety, Fire, and Vehicle Operations (VO) personnel with APCI drivers assisting in offloading. A cost estimate for offloading 48 mobile tankers per launch cycle and estimated total offloading cost for the period 1982 through 1991 follow.

* Does not include 7-percent escalation; with 7-percent escalation, the refund would be $8,346,368 for the period 1982 through 1991.

- Offloading Cost per Launch Cycle

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST AT $19.51/ MAN-HOUR (1982)
Safety	1	2	24	$ 468
Fire	4	2	96	1,872
VO	3	3	108	2,107
	*Cost per Mobile Tanker Transfer			$4,447

- Mobile Tanker Offloading Cost

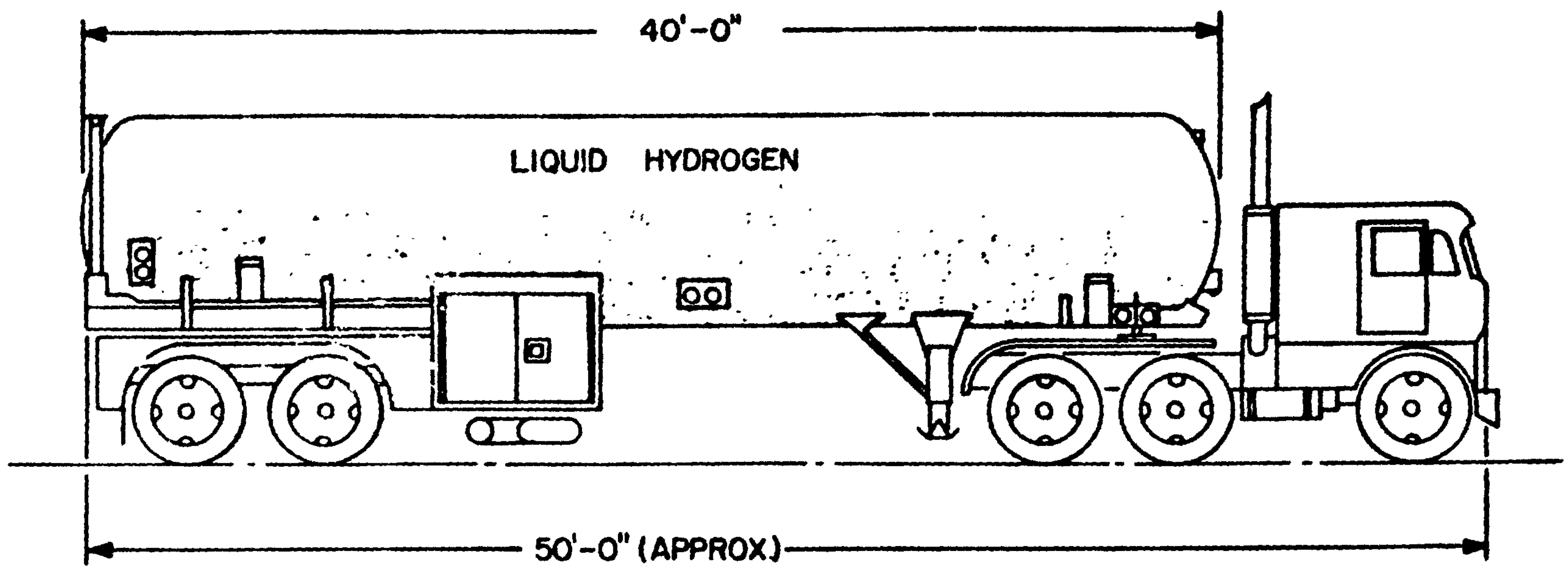
YEAR	COST/CYCLE	NUMBER OF CYCLES	COST/YEAR
1982	$4,447	13	$ 57,811
83	4,758	36	171,288
84	5,091	40	203,640
--	--	--	--
1991	8,175	40	327,001
	Total Offloading Cost		$2,318,400

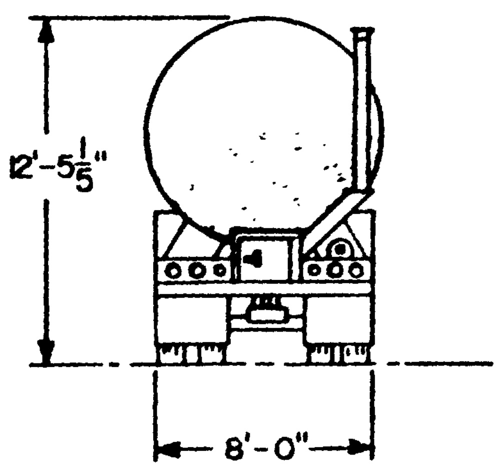
6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is measureably increased. For example, at 20 launches per year, a 50-percent reduction in operating and offloading costs and in transfer/efficiency losses would also be achieved. Estimated total cost, by category, for this option at 20 STS launches per year follows.

* Drivers are provided by APCI for this option.

Investment Cost	None
Operating Cost	$28,939,600
Maintenance Cost	None
Offloading Cost	1,159,200
Transfer/Efficiency Cost	7,003,000
TOTAL COST (20 LAUNCHES/YEAR)	$37,101,800





APCI STANDARD LH_2 MOBILE TANKER

SPECIFICATIONS:

MANUFACTURER:	AIR PRODUCTS & CHEMICALS INC., ALLENTOWN, PENN.
PRESSURE:	INNER VESSEL: 45 PSIG OPERATING OUTER VESSEL: FULL VACUUM
CAPACITY:	12,348 GALLONS W/5.9% ULLAGE (13,275 GALLONS GROSS)
EMPTY WT:	43,240 LBS.
FULL WT:	50,560 LBS.

FIGURE 10-1

APCI 13,000-GAL LH_2 MOBILE TANKER

APPENDIX 11

APPENDIX 11

OPTION 11 - APCI 13,000-GAL MOBILE TANKERS (F.O.B. KSC INVENTORY TANK)

1.0 CONCEPT OF OPERATION

Option 11 is based on the use of APCI tractors and 13,000-gal mobile tankers to transport LH_2 from New Orleans directly to a 125,000-gal LH_2 inventory tank at KSC. Subsequently, LH_2 would be transferred from the inventory tank to the storage spheres at Pads A and B using the seven existing KSC-owned 13,000-gal mobile tankers in combination with dedicated GSA tractors as in Option 5. The use of an inventory tank located outside the Pad A and Pad B perimeters permits APCI mobile tankers to fill the tank at their convenience without interrupting pad operations. The inventory tank would also permit transfer to the LH_2 storage spheres at Pads A and B at the most convenient time for KSC. The method of delivery for this option is f.o.b. destination as in Option 10. The basic LH_2 supply contract (NAS8-31034) would provide for paying APCI at the fixed mileage rate detailed in Appendix 10 through mid-1982. For APCI delivery f.o.b. KSC after that date, negotiation of a new contract price would be required.

The selection of a 125,000-gal inventory tank provides the capability for offloading and temporary storage of up to twelve 13,000-gal mobile tanker loads of LH_2. As mobile tankers would normally load and depart APCI in sets of four mobile tankers every 12 hours, the inventory tank could provide up to 36 hours delay in pad sphere loading without seriously disrupting or delaying APCI LH_2 delivery operations.

The use of an inventory tank and triple offloading increases transfer losses to approximately 80,000 gal for this option. To provide 500,000 gal of LH_2 per launch and to provide for transfer/efficiency losses, approximately fifty mobile tanker loads of LH_2 per launch cycle would be required. Four 13,000-gal tankers could be filled and depart APCI fill manifolds every 12 hours with 16 hours of travel time between APCI and KSC and 12-hour-maximum turnaround delay at KSC. Any delay of APCI tankers longer than 2 hours would require KSC to pay demurrage at the rate of $6.00 for each 15 minutes or fraction thereof. However, the inventory tank concept should eliminate demurrage altogether.

The proposed launch cycle would begin with each pad storage sphere containing 850,000 gal of LH_2 and with 125,000 gal of LH_2 in the inventory tank. When a launch occurs from Pad A, storage in Sphere A would be reduced to 350,000 gal. The day following launch, KSC 13,000-gal mobile tankers and GSA tractors would begin transporting LH_2 from the 125,000-gal inventory tank to storage Sphere A until the level of Sphere A is returned to 850,000 gal. Simultaneously, APCI 13,000-gal mobile tankers would be replacing LH_2 (f.o.b KSC) in the inventory tank as it is removed. This same procedure would be repeated for launches from Pad B.

2.0 INVESTMENT COST

Under this option, APCI tractors and 13,000-gal mobile tankers would deliver LH_2 from APCI to the inventory tank at KSC. Existing KSC 13,000-gal mobile tankers and GSA tractors would transfer LH_2 from the inventory tank to storage spheres at Pads A and B as in Option 4. KSC investment under this option would be limited to seven dedicated GSA tandem-axle diesel tractors and the inventory tank facility construction. GSA tractor costs for the seven KSC mobile tankers are detailed in Appendix 4. The Chicago Bridge and Iron Company provided an estimate of the cost of the inventory tank. The estimate was based upon a stainless steel inner sphere with 8 inches of perlite insulation, a carbon steel outer shell, a 2-percent-per-day boiloff rate, and a 105-psig operating pressure. As in Option 4, this option assumes the four NASA 13,000-gal LH_2 mobile tankers presently at APCI would be returned and that all seven mobile tankers would be available at no additional investment cost. Estimated total investment cost to the time at which KSC contracts would be awarded follows.

- <u>Equipment Investment</u>

	1977 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
Seven GSA Tractors (Appendix 4)	$ 287,000	$ 376,200
• <u>Cost Adjustment Factor (10 Percent)</u>		$ 37,600

- <u>Facility Construction Cost</u>

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
125,000-Gal Inventory Tank	$1,670,000	
Piping and Manifolds	150,000	
Parking Pads and Facilities	200,000	
	$2,020,000	$3,272,400
• <u>Design Fee (6 Percent)</u>		196,300
<u>Total Investment Cost</u>		$3,882,500

3.0 OPERATING COST

Operating cost associated with this option includes payment to APCI in accordance with the NAS8-31034 contract for LH_2 delivered f.o.b. KSC and the operating cost of the seven KSC 13,000-gal mobile tankers. APCI delivery costs are identical to Option 10 except that, due to high transfer/efficiency losses, fifty mobile tanker loads are required for each STS launch instead of the normal forty-eight. The operating cost for the seven KSC mobile tankers is detailed in Appendix 4. Total operating costs for APCI and KSC mobile tanker operations follow.

- APCI Mobile Tanker Cost (Appendix 10)

$57,879,300 x 50/48 =	$60,290,900

- KSC Mobile Tanker/Tractor Cost (Appendix 4)

	572,500
Total Operating Cost	$60,863,400

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes preventive and corrective maintenance of the seven KSC 13,000-gal mobile tankers, corrosion control of the inventory tank and associated piping, and labor cost for maintenance personnel associated with the inventory tank. The maintenance cost of the seven KSC mobile tankers is detailed in Appendix 4. Repainting and corrosion control of the inventory tank is required every 5 years at an estimated cost of $10,000 (1977 dollars). Approximately 20 hours per week are estimated as personnel requirements for normal maintenance of the inventory tank and associated piping and instrumentation. Based upon these factors, estimated maintenance cost for this option follows.

- <u>Seven KSC Mobile Tanker Maintenance (Appendix 4)</u> $684,000

- <u>Resurfacing Inventory Tank Cost (1987 Dollars)</u> $ 14,000

- <u>Inventory Tank Maintenance Personnel Cost</u>

YEAR	MAN-HOURS	COST/MAN-HOUR	COST/YEAR
1982	1,040	$19.51	$ 20,290
83	1,040	20.88	21,715
84	1,040	22.34	23,233
--	--	--	--
1991	1,040	35.87	37,305
	Inventory Tank Maintenance Cost		$280,300
	Total Maintenance Cost		$978,300

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), APCI driver, and GSA vehicle operator functions. APCI driver assistance is included at no cost to KSC. Fire and Safety personnel are required 1/2 hour and VO personnel are required 1 hour prior to and following each offloading operation. The fifty APCI mobile tankers would arrive for offloading in twelve sets of four tankers and one set of two tankers for a total of thirteen operations at the inventory tank. The seven KSC mobile tankers would operate in two sets (four and three mobile tankers each) to transfer LH_2 to the appropriate pad storage sphere in a maximum of fourteen offloading operations. Average time for each 13,000-gal offloading operation is estimated at 2 hours. Estimated total offloading costs for this option follow.

- Cost per Mobile Tanker Offloading Operation ($19.51/Man-Hour 1982 Dollars)

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST AT $19.51 MAN-HOUR (1982)
Safety	1	2	81	$ 1,580
Fire	4	3	324	6,321
VO	3	4	324	6,321
GSA Tractor Operation	7	2	196	3,823
	Total			$18,045

- Mobile Tanker Offloading Cost

YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$18,045	13	$ 234,585
83	19,308	36	695,088
84	20,659	40	826,360
-	-	-	-
1991	33,174	40	1,326,953
	Total Offloading Cost		$9,407,900

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is still marginal. For example, at 20 launches per year, no reduction in investment or maintenance costs would be realized; however, a 50-percent reduction in operating and offloading costs could be achieved. Transfer/efficiency losses would also be reduced by 50 percent except boiloff losses which would continue at a uniform rate for the inventory tank and mobile tankers. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$ 3,882,500
Operating Cost	$30,431,700
Maintenance Cost	$ 978,300
Offloading Cost	$ 4,703,900
Transfer/Efficiency Cost	$11,700,000
TOTAL COST (20 LAUNCHES/YEAR)	$51,696,400

APPENDIX 12

APPENDIX 12

OPTION 12 - 34,000-GAL RAILCARS

1.0 CONCEPT OF OPERATION

Option 12 is based on the use of 34,000-gal railcars to deliver LH_2 from APCI directly to the storage spheres at Pads A and B (Figure 12-1). The railcars would be KSC-owned, but transported by scheduled rail carrier. Eighteen operational railcars would be required with one additional railcar retained as a maintenance spare. Under this option, it is assumed that the four NASA-owned 34,000-gal railcars presently located at Lewis Research Center would be provided to KSC and that fifteen additional railcars and two idler cars would be procured. The eighteen operational LH_2 railcars would move together as a single, hazardous fuel unit with an idler car on each end of the column of railcars providing a safety buffer as required by DOT regulations. This arrangement would also facilitate expediting the switching of railcars between the four railway carriers involved in the rail movement between KSC and New Orleans. The railcars would be placed on a special 9-day round trip travel schedule.

Loadout at APCI for each 34,000-gal railcar would be 31,700 gal of LH_2 (allowing 6-percent ullage and a 6-percent water density safety factor). Depressurization, boiloff, and other transfer losses would reduce this volume by approximately 2,600 gal. Each 18-railcar group would then deliver 29,000 gal per railcar or 515,000 gal of LH_2 into the storage spheres at Pads A and B as required, leaving 500 gal of "heel" in each railcar.

APCI has LH_2 railcar loading facilities, however, the existing facilities must be expanded and tracks must be extended to accommodate rapid loading of eighteen railcars within 24 hours. The KSC Design Engineering (DE) concept for APCI rail facility upgrading without purchase of additional land is shown in Figure 12-2.

In addition, KSC railroad tracks need extensive repair and offloading facilities at Pads A and B would require modification and extension. The KSC DE concept for proposed railroad track modifications for Pads A and B are shown in Figure 12-3. The proposed railcar development schedule is shown in Figure 12-4.

The four NASA LH_2 railcars planned for use under this option were built by Linde and are in covered storage at LRC (Figure 2-2). Each existing railcar has a gross capacity of 36,100 gal and a stainless steel inner liner, carbon steel outer casing, mylar superinsulation, 0.5-percent-per-day boiloff rate, and a maximum 100-psig operating pressure. The fifteen additional railcars would have similar characteristics except that perlite or similar insulation could be used instead of superinsulation. Each railcar would be equipped with standard NASA 2-inch bayonet couplings with flexible hoses for offloading. This flexible off-loading hose capability would permit connecting to the existing 2-inch LH_2 manifolds at Pads A and B with simultaneous offloading of two railcars. With the 34,000-gal railcars pressurized to 45 psig, offloading flow time should be approximately 2 hours per railcar offloading operation.

The 18-railcar resupply cycle starts with each pad storage sphere containing 850,000 gal of LH_2. When a launch from Pad A occurs, storage in Sphere A is reduced to 350,000 gal. The day following launch, or any specified time of the 9-day launch cycle, the eighteen railcars would arrive and refill Sphere A to the 850,000-gal level. This procedure would be repeated for launches from Pad B. Allowing for 24-hour offloading at KSC, 24-hour onloading at APCI, and 84-hour travel time between APCI and KSC, the resupply cycle would require 9 days. A proposed traffic model for this option is shown in Figure 12-5.

2.0 INVESTMENT COST

The estimated cost to build the fifteen additional 34,000-gal LH_2 railcars required for this option was discussed with LOX Equipment Company, Linde Division of Union Carbide Corporation, and Russell Engineering. LOX and Russell indicated 34,000-gal LH_2 railcars could be built using perlite or similar insulation for approximately \$300,000 each (1977 dollars). Linde also indicated that the railcars would cost approximately \$300,000 each with superinsulation, providing the expensive instrumentation packages on the four existing NASA railcars were not required. The refurbishment cost for the four existing NASA LH_2 railcars is estimated at \$10,000 each (1977 dollars). KSC DE estimated that KSC and APCI railroad track repair and modifications, combined with upgrading of APCI piping and transfer lines would total approximately $4,000,000 (1977 dollars). Based upon these figures, the estimated investment cost for this option follows.

- Equipment Investment Cost

	1977 VENDOR ESTIMATE (VE)	1981 BUDGET ESTIMATE
Fifteen 34,000-Gal Railcars	$ 4,500,000	$ 5,898,500

- Cost Adjustment Factor (10 Percent) $ 589,900

- Four 34,000-Gal Railcars (Rehabilitate) $ 52,000

- Facility Construction Cost

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
KSC Track Modifications and Extensions	$ 2,669,000	
APCI Track Extensions	248,818	
APCI Piping and Transfer Lines	1,191,176	
	$ 4,108,994	$ 6,656,600

- Design Fee (6 Percent) $ 399,400

Total Investment Cost $ 13,544,400

3.0 OPERATING COST

The operating cost for LH_2 delivery by 34,000-gal railcar under this option includes freight charges for each railcar, APCI Terminal and Administration (T&A) charges ($32,100 per year), and trackmobile costs. Florida East Coast railroad has quoted a railcar freight rate of $2,157 (1977 dollars) per round trip to KSC

Transportation Services. This price includes $183 credit for use of a shipper-owned car plus $40 for switching charges. The T&A charges include the standard APCI charge for salary, office space, and administrative processing of KSC-owned LH_2 tankers stated in previous options. KSC trackmobile costs under this option are assumed to be similar to Option 2. Based on these estimates, the operating cost for this option follows.

- Railcar Operating Cost

YEAR	LAUNCHES	COST/ RAILCAR ROUND TRIP	RAILCAR TRIPS	COST/YEAR
1982	13	$3,025	234	$ 707,850
83	36	3,237	648	2,097,576
84	40	3,463	720	2,493,360
--	--	--	--	--
1991	40	5,561	720	4,003,920
		Railcar Operating Cost		$28,388,400

- APCI T&A Charges (Appendix 6) $ 665,500

- Trackmobile Cost (Appendix 2) $ 157,600

Total Operating Cost $29,211,500

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes preventive and corrective maintenance of the LH_2 railcars and the KSC trackmobile. Maintenance cost factors and annual maintenance cost for each of these items are detailed in Appendix 2. Estimated total maintenance cost for this option follows.

- Railcar Maintenance Cost

YEAR	MAINTENANCE COST/ RAILCAR	CARS IN SERVICE	COST/YEAR
1982	$4,067	19	$ 77,273
83	4,352	19	82,688
84	4,656	19	88,464
--	--	--	--
1991	7,478	19	142,072
	Railcar Maintenance Cost		$1,068,700

- Trackmobile Maintenance Cost (Appendix 2) $ 41,000

Total Maintenance Cost	$1,109,700

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and trackmobile operator functions as in Appendix 2. Trackmobile operators are included in the operations cost. With simultaneous offloading of two railcars at 2 hours per offloading operation, the total offloading time for the eighteen railcars should average about 18 hours under this option. Fire and Safety personnel are required in each area 1/2 hour prior to and following offloading operations. VO personnel are required in each area 1 hour prior to and following offloading operations to establish security, prepare the sites for operation, and shut down the sites following operations. Estimated cost factors and total offloading costs follow.

- Cost per 18-Railcar Offloading Operation ($19.51/Hour 1982)

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST/TRANSFER
Safety	1	19	19	$ 370
Fire	4	19	19	1,483
Vehicle Operations	3	20	60	1,170
	Cost per 18-Railcar Transfer			$ 3,023

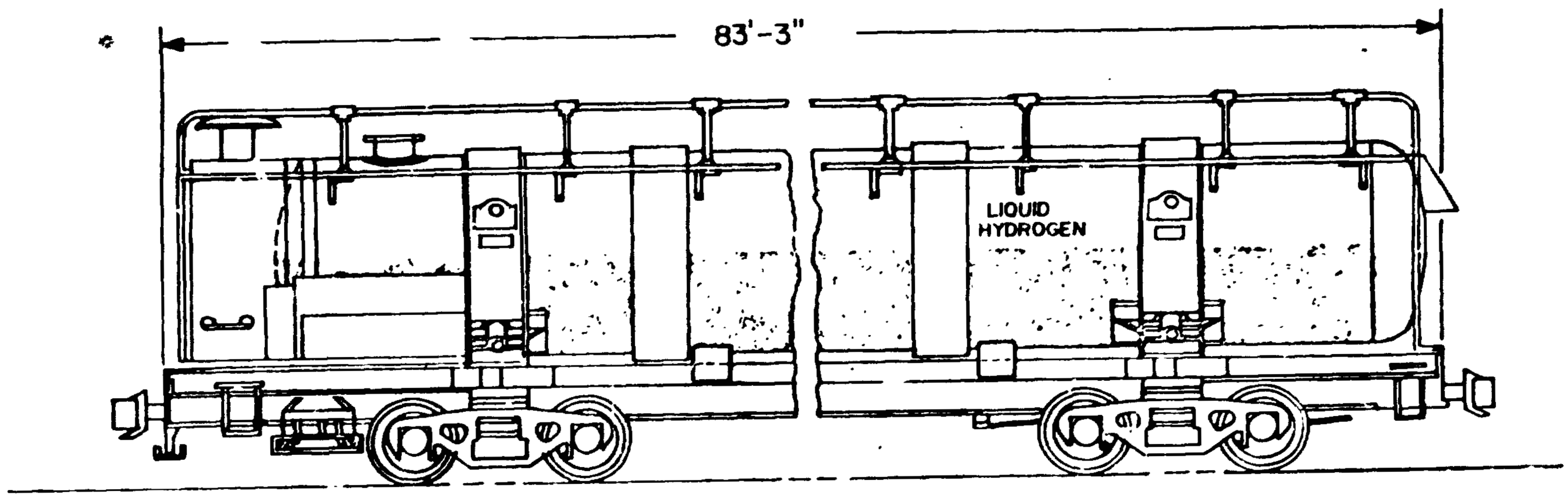
- Railcar Offloading Cost

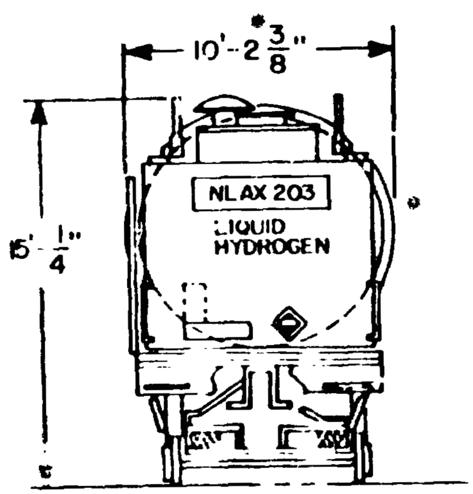
YEAR	COST/TRANSFER	OF CYCLES	COST/YEAR
1982	$3,023	13	$ 39,299
83	3,235	36	116,460
84	3,461	40	138,440
--	--	--	--
1991	5,558	40	222,320
	Total Offloading Cost		$ 1,575,600

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is moderately increased. For example, at 20 launches per year, investment could be reduced to six railcars and facilities could be reduced by 75 percent. In addition, an estimated 50-percent reduction in operating and offloading costs could be achieved. Transfer/efficiency losses could also be reduced by 50 percent except boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$ 4,126,000
Operating Cost	$ 14,605,800
Maintenance Cost	$ 584,100
Offloading Cost	$ 787,800
Transfer/Efficiency Cost	$ 6,608,000
TOTAL COST (20 LAUNCHES/YEAR)	$ 26,711,700





SPECIFICATIONS

PRESSURE - INNER VESSEL: 100 PSIG OPERATIONS

OUTER VESSEL: FULL VACUUM

CAPACITY - (34,000 GAL GROSS)

EMPTY WEIGHT - 150,000 LBS. (APPROX)

FIGURE 12-1

34,000 LH_2 RAILCAR

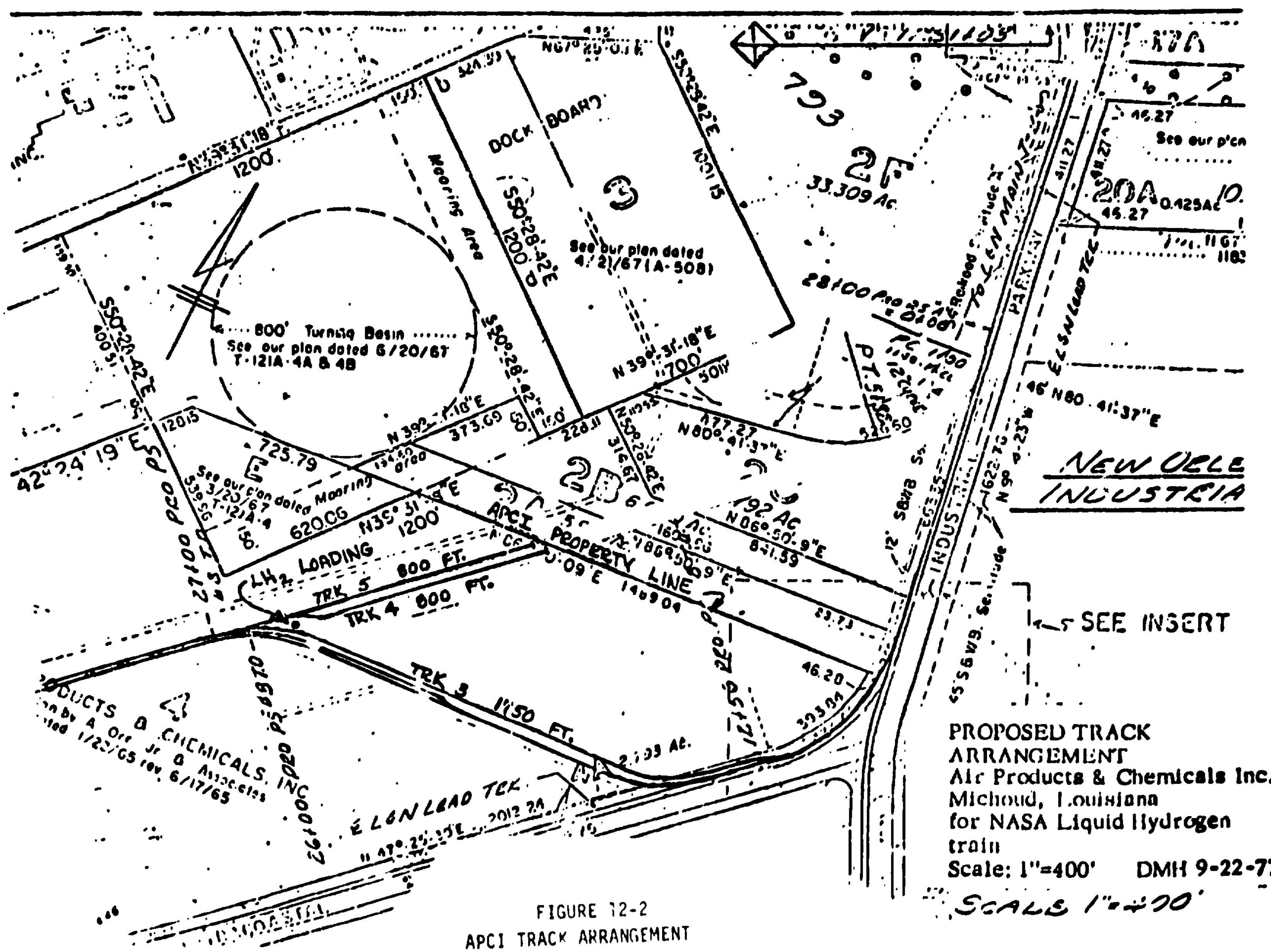


FIGURE 12-2
APCI TRACK ARRANGEMENT

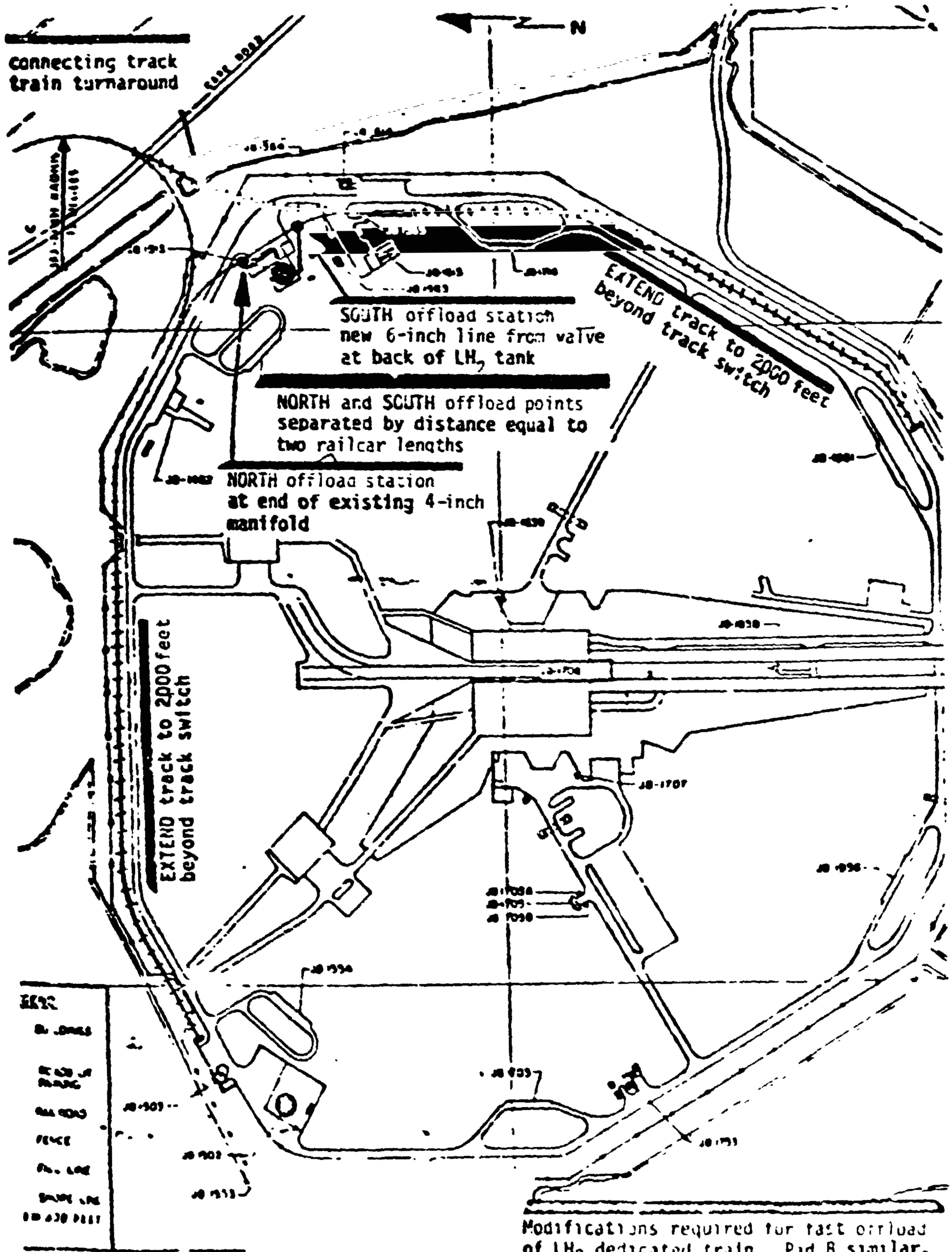


FIGURE 12-3
KSC RAILROAD TRACK MODIFICATIONS

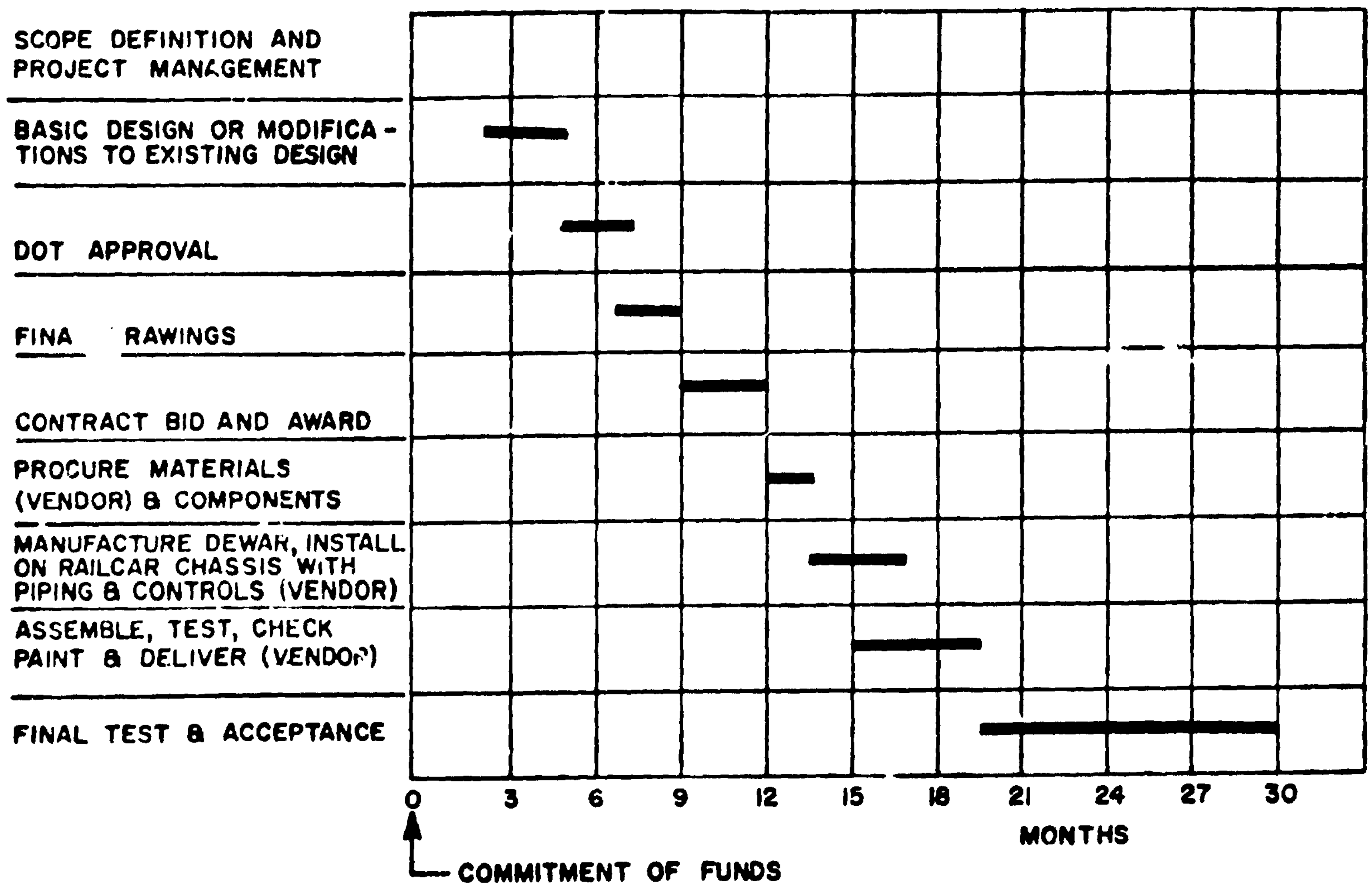


FIGURE 12-4

34,000-GAL RAILCAR DEVELOPMENT SCHEDULE

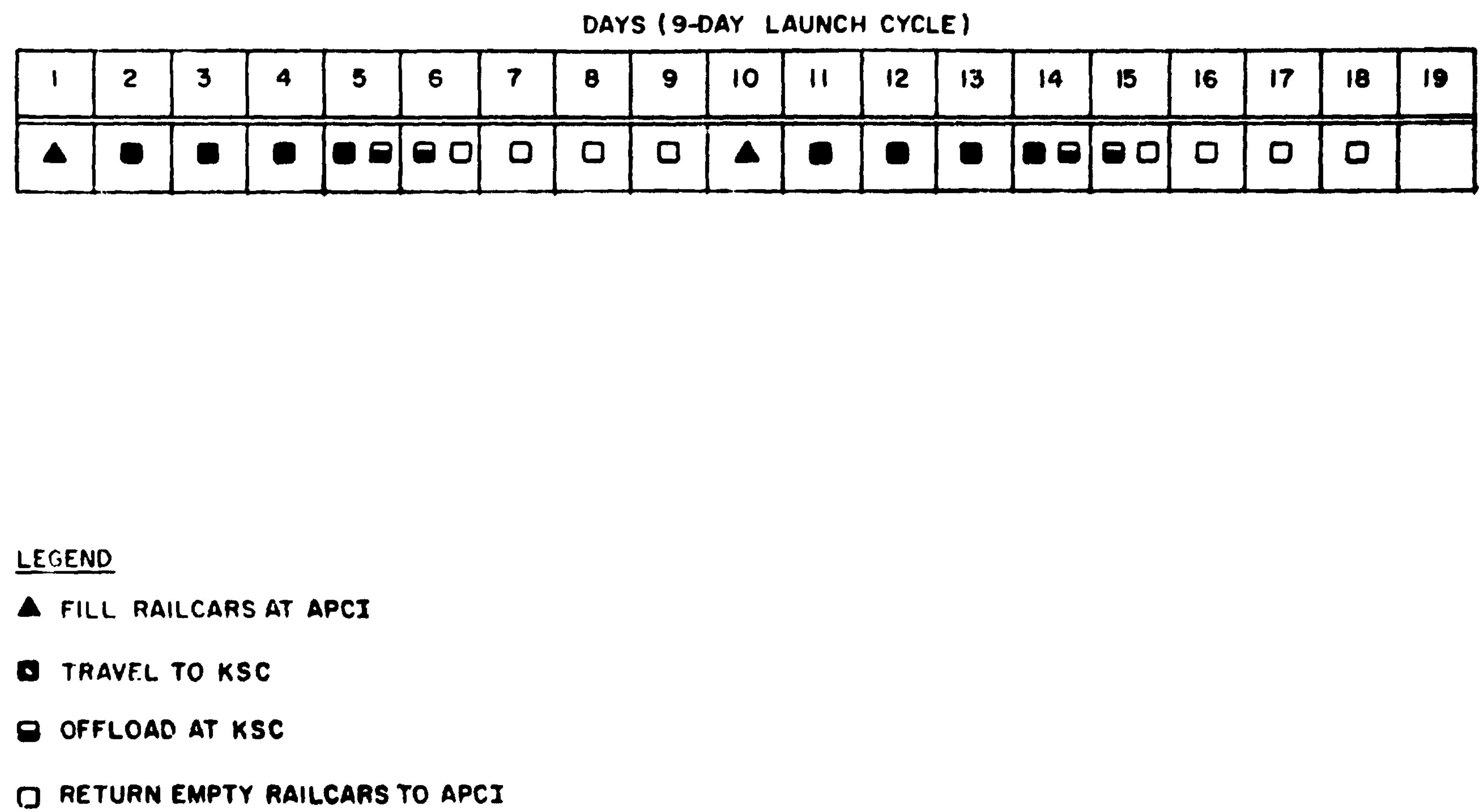


FIGURE 12-5

9-DAY RAILCAR TRAFFIC MODEL

APPENDIX 13

APPENDIX 13

OPTION 13 - SPECIAL TRAIN (EIGHTEEN 34,000-GAL RAILCARS)

1.0 CONCEPT OF OPERATION

Option 13 is based on the use of a special 18-railcar train to deliver LH_2 from APCI directly to storage spheres at Pads A and B. The proposed special train would consist of one 2,000-horsepower diesel locomotive, two idler cars, one caboose, and eighteen 34,000-gal LH_2 railcars (Appendix 12, Figure 12-1). The entire train would be KSC-owned, but operated by Florida East Coast (FEC) railroad personnel. As in Option 12, it is assumed that the four NASA-owned 34,000-gal railcars presently located at Lewis Research Center would be provided to KSC and that fifteen additional railcars (one maintenance spare) would be procured. The train would be placed on a special schedule with maximum speed of 30 miles per hour for safety purposes and to minimize the probability of catastrophic accident. Loadout at APCI for each 34,000-gal railcar would be 31,700 gal of LH_2 (allowing 6-percent ullage and a 6-percent water density safety factor). Depressurization, boiloff, and other transfer losses would amount to approximately 2,300 gal. Each 18-railcar train should then deliver 29,000 gal per railcar or 522,000 gal of LH_2 into the storage spheres at Pads A and B. With 400-gal of "heel" retained in each railcar. As in Option 12, the idler cars would be used as safety buffers on each end of the column of LH_2 railcars.

APCI has LH_2 railcar loading facilities, however, the existing capabilities must be expanded and tracks must be extended to accommodate rapid loading of the eighteen railcars of the special train within 24 hours. LH_2 loading of the special train at APCI would be accomplished by placing eight railcars on track 4, eight on track 5, and the remaining two on track 3 (Figure 13-1). Four 34,000-gal railcars would be filled simultaneously from the APCI LH_2 loading station servicing tracks 4 and 5. Estimated fill time for each group of four railcars is 4 hours. As each group of railcars is filled, the group would be moved to track 3, exchanged with empty railcars, and reassembled into a complete train. Estimated loading time for all eighteen railcars is 20 hours.

To offload the special 18-railcar train, the existing KSC railroad track sections (east-west and north-south) at each pad would be extended to 2,000 feet beyond the track switches and a second (south) offloading manifold would be added at each pad sphere (Figure 13-2). Offloading would be accomplished by moving the entire special train onto the 2,000-foot north-south extension of the tracks. All railcars would then be moved in column to the pad offload stations, connected by flexible hose to the north and south 2-inch manifolds at each sphere, and two railcars would be offloaded simultaneously. Offloaded railcars would be reassembled into an empty train on the 2,000-foot east-west track extensions. At 45 psig, estimated offloading flow time is 1.5 hours with an additional 0.5 hours required for positioning, purging, and connecting the railcars at the offload manifolds.

The special 18-railcar train resupply cycle starts with each pad storage sphere containing 850,000 gal of LH_2. When a launch from Pad A occurs, storage in Sphere A would be reduced to 350,000 gal. The day following launch, or at any specified time, the special train would arrive and refill Sphere A to the 850,000-gal level. This procedure would be repeated for launches from Pad B. Allowing for 24-hour offloading at KSC, 24-hour onloading at APCI, and 30-hour travel between APCI and KSC, the resupply cycle will require 108 hours. A proposed traffic model for this option is shown in Figure 13-3.

2.0 INVESTMENT COST

Investment cost for this option includes the purchase of a locomotive, two idler cars, a caboose, and fifteen 34,000-gal railcars; refurbishment of the four existing NASA railcars; construction of additional railroad track and onloading facilities at APCI; and consumption of additional railroad track and offloading facilities at KSC. The estimated cost of the locomotive, idler cars, and caboose provided by KSC Transportation Services follows. All other costs are detailed in Appendix 12. Estimated total investment cost for this option also follows.

- Equipment Investment

	1977 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
One Locomotive (2,000 Horsepower)	$ 490,000	$ 642,300
Fifteen 34,000-Gal Railcars	4,500,000	5,898,500
Four NASA Railcars (Rehabilitated)	40,000	52,400
Two Idler Cars (Used)	40,000	52,400
One Caboose	45,000	58,900
	$5,115,000	$6,704,500
- Cost Adjustment Factor (10 Percent)		670,500
- Facilities Construction Cost (Appendix 12)		6,656,600
- Design Fee (Appendix 12)		339,400
Total Investment Cost		$14,431,000

3.0 OPERATING COST

The operating cost for LH_2 delivery by special 18-railcar train under this option includes railroad freight charges for each railcar, operating crew cost, fuel cost, and APCI Terminal and Administration (T&A) charges. FEC railroad has quoted KSC Transportation Services a special train rate of $43,000 (1977 dollars) per round trip. This price includes crew cost, switching charges, and credits for shipper-owned cars. The estimated fuel consumption for the 2,000-horsepower locomotive is 3,000 gallons of diesel fuel per round trip. At the 1977 KSC cost of $0 40 per gallon, diesel fuel cost is estimated at $1,200 per round trip. APCI T&A charges for clerical salary, office space, and administrative processing of railcars is detailed in Appendix 6 and is considered standard for all semitrailer and railcar options. Projected to 1982, the estimated operating cost for this option follows.

- 18-Railcar Special Train Operating Cost ($62,322 per Round Trip 1982 Dollars)

YEAR	SPECIAL TRAIN COST/TRIP	NUMBER OF TRIPS	COST/YEAR
1982	$ 62,322	13	$ 810,186
83	66,684	36	2,400,624
84	71,352	40	2,854,080
--	--	--	--
1991	114,576	40	4,583,028
	18-Railcar Special Train Operating Cost		$32,493,100

- APCI T&A Cost (Appendix 6) 665,500

Total Operating Cost $33,158,600

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes preventive and corrective maintenance for the locomotive, idler cars, and caboose combined with periodic refurbishment of the LH_2 railcars. Maintenance and refurbishment costs for 34,000-gal LH_2 railcars are detailed in Appendix 2 and are estimated to be $4,067 per railcar in 1982. Discussion with KSC Transportation Services indicates that maintenance of the locomotive, idler cars, and caboose would probably be accomplished on a contract basis with FEC. Estimated maintenance cost factors and total maintenance cost for this option follow.

- Maintenance Cost Factors

Engine, Idler Cars, and Caboose (1982 Dollars)

	COST/YEAR
Preventive Maintenance - 110 Man-Hours @ \$19.51/Man-Hour	\$2,146
Corrective Maintenance - 200 Man-Hours @ \$19.51/Man-Hour	3,902
Materials (Includes Cleaning)	500
Major Engine Overhaul - \$5,000 every 5 Years	1,000
Maintenance Cost	\$7,548

- Railcar Maintenance Cost (19 Railcars)

YEAR	MAINTENANCE/ RAILCAR/YEAR	RAILCAR MAINTENANCE TOTAL	ENGINE, IDLER, CABOOSE COST/YEAR	COMBINED COST/YEAR
1982	4,061	\$ 77,273	\$ 7,548	\$ 88,421
83	4,352	82,688	8,076	90,764
84	4,656	88,464	8,641	97,105
--	--	-	--	--
1991	7,478	142,082	13,876	155,958
		Total Maintenance Cost		\$1,171,500

5.0 OFFLOADING COST

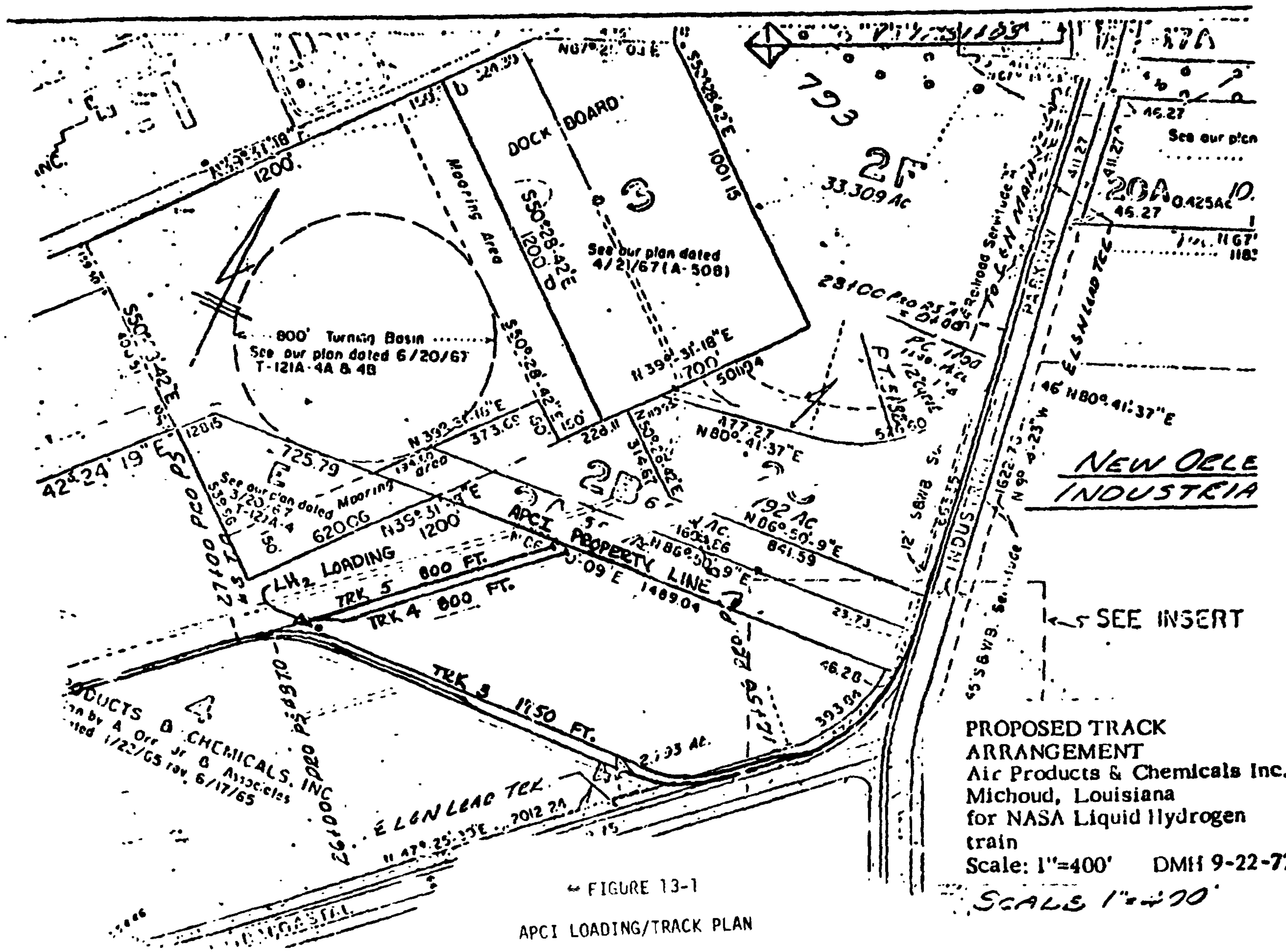
Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and diesel locomotive operator functions. Except for the use of the 2,000-horsepower locomotive instead of the trackmobile, offloading operations and procedures are identical to Option 12. As both trackmobile and locomotive operators are included in operating costs, the offloading procedures and costs are identical to those detailed in Appendix 12.

0 18-Railcar Special Train Offloading Cost (Appendix 12)	$1,575,600

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is reduced dramatically. For example, at 20 launches per year, investment and maintenance costs would remain unchanged, however, an estimated 50-percent reduction in operating and offloading costs could be achieved. Transfer/efficiency losses could also be reduced by 50 percent except boil-off losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$14,431,000
Operating Cost	16,579,300
Maintenance Cost	1,171,500
Offloading Cost	787,800
Transfer/Efficiency Cost	5,800,000
TOTAL COST (20 LAUNCHES/YEAR)	$38,769,600



← FIGURE 13-1

APCI LOADING/TRACK PLAN

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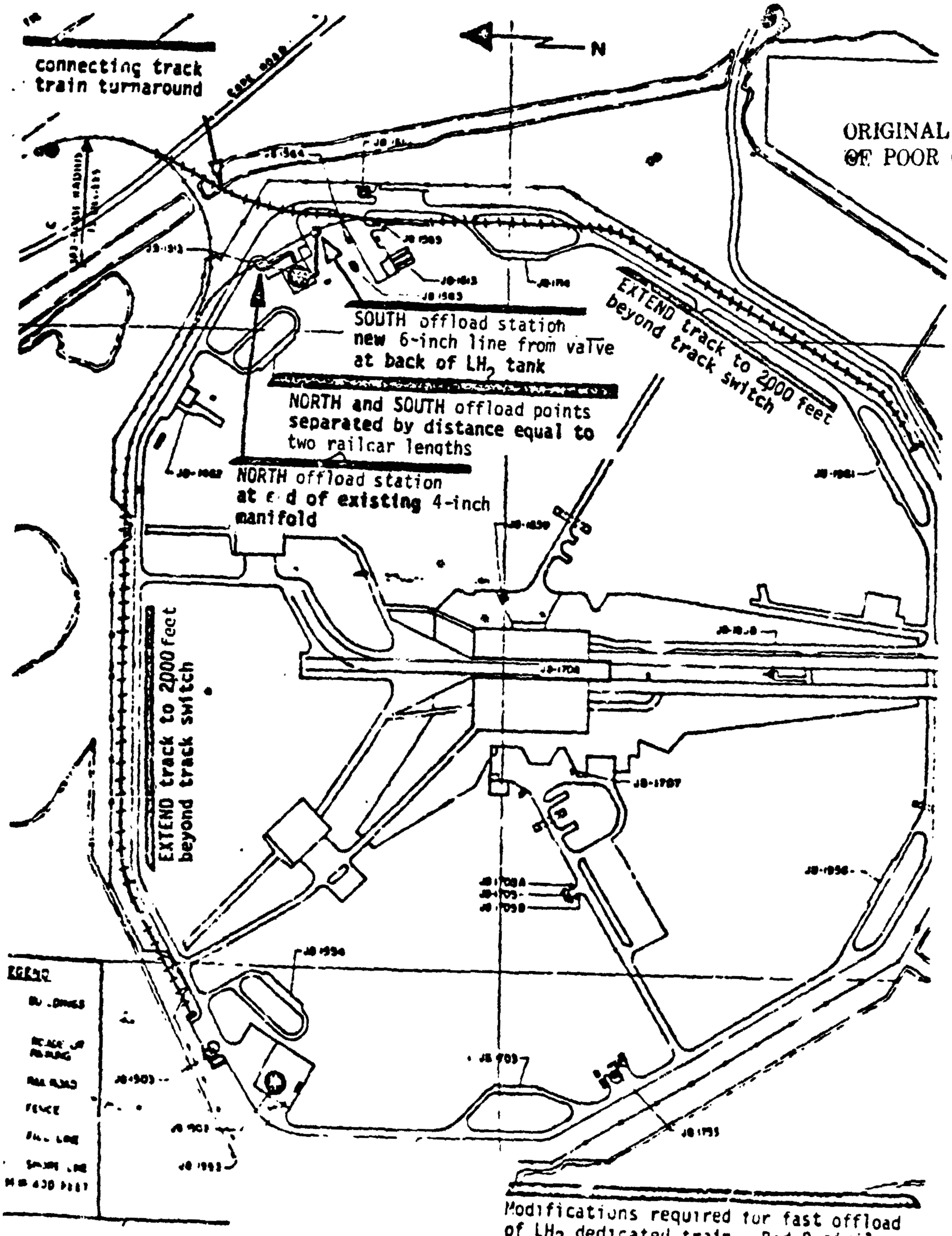
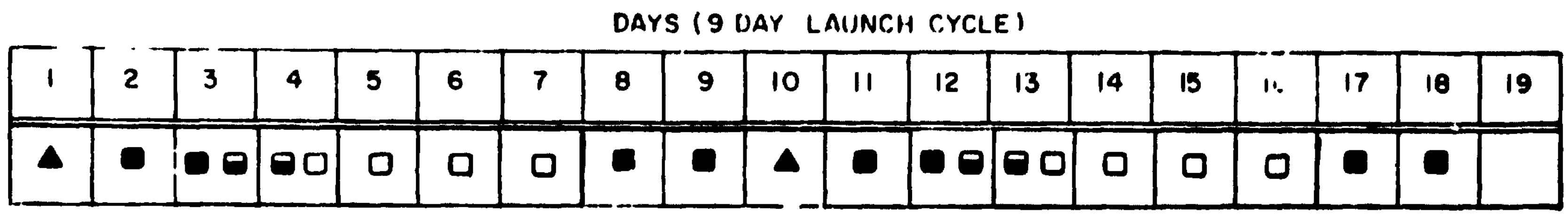


FIGURE 13-2
PAD RAILROAD TRACK EXTENSIONS

C-3



LEGEND

▲ ONLOAD - APCI

■ TRAVEL TO KSC/APCI

OFFLOAD - KSC

□ DEAD TIME

FIGURE 13-3

18-RAILCAR
SPECIAL TRAIN TRAFFIC DIAGRAM

APPENDIX 14

APPENDIX 14

OPTION 14 - SPECIAL TRAIN (THIRTY -SIX 34,000-GAL RAILCARS)

1.0 CONCEPT OF OPERATION

Option 14 is based on the use of a special 36-railcar train to deliver LH_2 from APCI directly to the storage spheres at Pads A and B. The proposed special train would consist of two 2,000-horsepower diesel locomotives, two idler cars, one caboose, and thirty-six 34,000-gal LH_2 railcars (Appendix 12, Figure 12-1). The special train would be KSC-owned, but operated by Florida East Coast (FEC) railroad personnel. Under this option, it is assumed that the four NASA-owned 34,000-gal railcars presently located at Lewis Research Center would be provided to KSC and that thirty-three (one maintenance spare) additional railcars would be procured. This option represents a significant increase in initial investment cost, however, it permits reduction of special train trips by 50 percent as the thirty-six railcars could deliver sufficient LH_2 to support two STS launches, one from each pad. Loadout at APCI for each 34,000-gal railcar would be 31,700 gal of LH_2 (allowing 6-percent ullage and a 6-percent water density safety factor). Depressurization, boiloff, and other transfer/efficiency losses would amount to approximately 3,100 gal. Each special 36-railcar train would then deliver 28,500-gal per railcar of 1,026,000 gal of LH_2 per special train into the storage spheres at Pads A and B as required.

As the total LH_2 loadout at APCI (1,141,200 gal) under this option exceeds the maximum 500,000 pounds (844,700 gal) which can be removed from the two 500,000-gal APCI storage spheres at one time, onloading of the railcars at APCI would necessitate some delay. The LH_2 plant regenerative capacity of APCI is 30 tons (100,000 gal) per day which will require approximately 3 additional days of APCI LH_2 production and, subsequently, a 3-day onloading time delay for the special 36-railcar train. This delay would cause the increased transfer/efficiency losses indicated previously.

APCI has LH_2 railcar loading facilities, however, the existing facilities must be expanded and tracks must be extended to accommodate rapid loading of the thirty-six railcars within 72 hours. In addition, KSC railroad tracks and offloading facilities at Pads A and B would require modification and extension. Proposed railroad track modifications at APCI are shown in Figure 13-1. Proposed railroad track modifications for KSC, Pads A and B are shown in Figure 13-2.

For onloading at APCI, eight 34,000-gal LH_2 railcars each would be positioned on tracks 4 and 5 and the remaining twenty railcars would be positioned on track 3. Four railcars would be filled simultaneously (two each from tracks 4 and 5) from the APCI LH_2 railcar loading facility as in Option 13. Loaded railcars would be moved to the L & N Railroad switching track and formed in a special train for return to KSC approximately 3 days later. Offloading at KSC would be identical to Option 12 as eighteen railcars each would be positioned at Pads A and B. Offloaded railcars would be moved to a designated KSC holding area for subsequent deliveries.

The special 36-railcar train resupply starts with each pad storage sphere containing 850,000 gal of LH_2. When a launch occurs from Pad A, the storage in Sphere A would be reduced to 350,000 gal. Nine days later, when a launch occurs from Pad B, storage would be reduced to 350,000 gal in Sphere B. The day following the second launch, or at any specified time of the 9-day launch cycle, the special train would arrive and refill both the Pad A and Pad B storage spheres to 850,000 gal. This procedure would be repeated after every two launches. Allowing 24-hour offloading at KSC, 72-hour onloading at APCI, and 30-hour travel between APCI and KSC, the resupply cycle will require 6-1/2 days. A proposed traffic model for this option is shown in Figure 14-1.

2.0 INVESTMENT COST

The investment cost associated with this option includes the procurement of two locomotives, two idler cars, one caboose, thirty-three 34,000-gal LH_2 railcars; refurbishing cost for the four existing NASA LH_2 railcars; and expanded rail facilities construction at APCI and KSC. Except for the quantities of equipment required, the equipment and facilities construction costs are identical to those described in Option 13. Estimated total investment cost follows.

- **Equipment Investment Cost**

	1977 VENDOR ESTIMATE (VE)	1981 BUDGET ESTIMATE (1.91 VE)
Two Diesel Locomotives	$ 980,000	$ 1,284,500
Thirty-Three LH_2 34,000-Gal Railcars	9,900,000	12,976,900
Four NASA Railcars (Rehabilitated)	40,000	52,000
Two Idler Cars	40,000	52,000
One Caboose	45,000	58,900
Total	$11,005,000	$14,424,300

- Cost Adjustment Factor (10 Percent)	1,442,400
- Facilities Construction Cost (Appendix 13)	6,656,600
- Design Fee (6 Percent) (Appendix 13)	399,400
Total Investment Cost	$22,922,700

3.0 OPERATING COST

The operating cost for LH_2 delivery by special 36-railcar train under this option includes railroad freight charges for each train, operating crew cost, fuel cost, and APCI Terminal and Administration (T&A) charges. The T&A charges include standard APCI salary, office, and administrative processing charges for mobile tankers and railcars. As detailed in Appendix 6, KSC Transportation Services estimates the round trip freight and crew cost for the special 36-railcar train at $63,000 (1977 dollars). FEC estimates that, with two locomotives and thirty-six railcars, diesel fuel usage will increase approximately 50 percent per round trip; however, the 50-percent reduction in round trips required under this option should result in a net overall fuel savings. Based on these estimates, the cost factors and operating cost for this option follow.

- Operating Cost Factors

  Train Cost/Round Trip $63,000 (1977)

  Fuel Cost/Round Trip 1,200 (1977)

  Round Trip Time . . . . 6-1/2 Days

- 36-Railcar Special Train Cost ($90,885 per Round Trip (1982 Dollars)

YEAR	SPECIAL TRAIN COST/TRIP	NUMBER OF TRIPS	COST/YEAR
1982	$ 90,885	7	$ 636,195
83	97,247	18	1,750,446
84	104,054	20	2,081,080
--	--	--	--
1991	167,085	20	3,341,700
	Special Train Cost		$23,737,800

- APCI T&A Charge (Appendix 6) 665,600

  Total Operating Cost $24,403,300

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes preventive and corrective maintenance for the two locomotives, idler cars, caboose, and LH_2 railcars. The estimated maintenance cost factors for each of these items of equipment are detailed in Appendix 13. Maintenance cost factors for the additional special train equipment are detailed in Appendix 13. Maintenance cost factors for the additional special train equipment and overall maintenance cost for this option follow.

- Maintenance Cost Factors (Appendix 13)

  Engine, Idler Cars, and Caboose (1982 Dollars)

	COST/YEAR
Preventive Maintenance - 150 Man-Hours @ $19.51/Man-Hour	$2,926
Corrective Maintenance - 200 Man-Hours @ $19.51/Man-Hour	3,902
Materials (Includes Cleaning)	500
Major Engine Overhaul (2 X Appendix 13)	2,000
Maintenance Cost	$9,328

- Railcar Maintenance Cost (Appendix 12) $4,067

- Railcar Maintenance Cost (37 Railcars)

YEAR	MAINTENANCE/ RAILCAR/YEAR	RAILCAR MAINTENANCE TOTAL	ENGINE, IDLER CABOOSE COST/YEAR	COMBINED COST/YEAR
1982	$4,067	$150,479	$ 9,328	$ 159,807
83	4,352	161,024	9,981	171,005
84	4,656	172,272	10,679	182,951
--	--	--	--	--
1991	7,478	76,686	17,149	293,835
		Total Maintenance Cost		$2,208,300

5.0 OFFLOADING COST

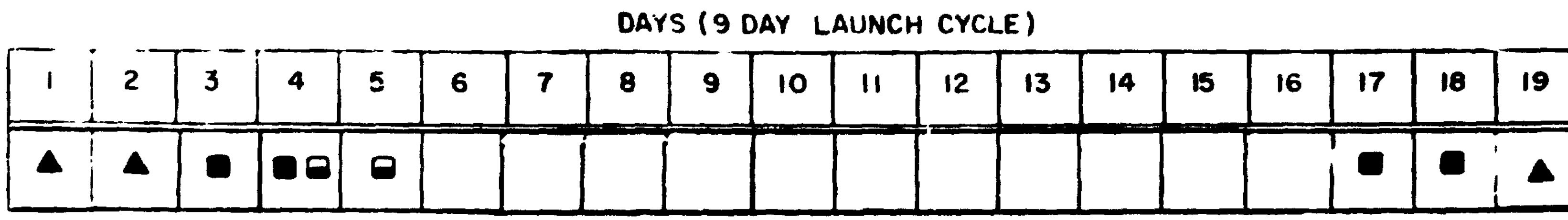
Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and railcar operator functions. Personnel and operational requirements for offloading at each pad are identical to Option 13. Although two identical offloading operations must be performed for each special 36-railcar train trip, the operations are required only half as often. Detailed costs for each offloading operation are detailed in Appendix 13.

- Offloading Cost (Appendix 13) $1,575,600

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is reduced dramatically. For example, at 20 launches per year, investment and maintenance costs would remain unchanged; however, an estimated 50-percent reduction in operating and offloading costs could be achieved. Transfer/efficiency losses could also be reduced by 50 percent except boil-off losses which would increase because of delayed onloading at APCI. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	$22,922,700
Operating Cost	12,201,600
Maintenance Cost	2,208,300
Offloading Cost	787,800
Transfer/Efficiency Cost	6,600,000
TOTAL COST (20 LAUNCHES/YEAR)	$44,720,400



LEGEND

ONLOAD - APCI

TRAVEL TO KSC/APCI

OFFLOAD - KSC

DEAD TIME

FIGURE 14-1
36-RAILCAR
SPECIAL TRAIN TRAFFIC DIAGRAM

APPENDIX 15

APPENDIX 15

OPTION 15 - COMBINED ASSETS - RAILCARS

1.0 CONCEPT OF OPERATION

Option 15 is based on the use of the seven existing KSC-owned 13,000-gal mobile LH_2 tankers and the four existing NASA-owned 34,000-gal railcars at Lewis Research Center, combined with six additional 34,000-gal LH_2 railcars to support 40 STS launches per year. Seven additional 34,000-gal railcars (six operational and one maintenance spare) would be procured incrementally as needed to support the launch rate actually achieved. The seven 13,000-gal mobile tankers would be transported by common carrier tractors on a 56-hour round trip schedule. The ten operational 34,000-gal railcars would be transported by scheduled railroad on a special 9-day round trip basis as in Option 12.

To provide 500,000 gal of LH_2 per launch and to provide for 47,800 gal in transfer/efficiency losses, a total of 551,000 gal of LH_2 would be loaded in KSC mobile tankers and railcars at APCI. Delivery of LH_2 directly into storage spheres at Pads A and B would be accomplished during days 1 through 7 by mobile tankers, and on a specified day of the launch cycle for railcars with no deliveries on the day preceeding the (or on the actual) launch date. To achieve this delivery rate, 20 mobile tanker loads of LH_2 would be required. Seven 13,000-gal tankers would be filled and would depart APCI fill manifolds and arrive at KSC on the first day following launch and the fourth day following launch, with only six mobile tankers scheduled to arrive on the seventh day following launch. The proposed traffic model to support the 13,000-gal LH_2 mobile tanker traffic is shown in Appendix 6, Figure 6-1. A proposed 9-day transportation model to support the 34,000-gal railcar traffic is shown in Appendix 12, Figure 12-5.

Under this option, each 13,000-gal LH_2 tanker would be loaded with 11,700 gal of LH_2 by APCI (assuming 6-percent ullage and a 6-percent water density safety fill factor). Depressurization, boiloff, and other transfer losses would amount to approximately 1,025 gal. Each mobile tanker would then deliver approximately 10,675 gal of LH_2 into the KSC storage spheres each round trip.

Loadout at APCI for each of the ten 34,000-gal railcars would be 31,700 gal of LH_2 (allowing 6-percent ullage and a 6-percent water density safety factor). Depressurization, boiloff, and other transfer losses would amount to approximately 2,600 gal. Each railcar would then deliver 29,100 gal of LH_2 into the storage spheres at Pads A and B as required. Movement of the LH_2 railcars for offloading operations would be accomplished with the KSC trackmobile.

The proposed launch cycle would begin with the LH_2 storage spheres at each pad containing 850,000 gal of LH_2. When a launch occurs from Pad A, storage in Sphere A is reduced to 350,000 gal Beginning the day following launch and continuing for the next 7 days, twenty 13,000-gal mobile tanker loads of LH_2 and ten 34,000-gal railcars would arrive at Pad A until Sphere A storage is returned to 850,000 gal. The same procedure would be repeated for each launch from Pad B. APCI mobile tankers with delivery f o.b. KSC could be used to provide backup support during incremental procurement of additional railcars.

2.0 INVESTMENT COST

Estimated investment cost to support this option consists of the purchase of seven additional 34,000-gal LH_2 railcars, some modifications to KSC and APCI railroad tracks and facilities to facilitate rapid onloading/offloading of ten railcars, and refurbishing of the four NASA-owned 34,000-gal railcars. The seven existing KSC-owned 13,000-gal mobile tankers and the four NASA-owned 34,000-gal railcars at Lewis Research Center are assumed to be available and serviceable in 1982. As common carrier tractors are used with this option, no additional trucks are required. Cost estimates for procuring new 34,000-gal railcars and for rehabilitating the four NASA-owned railcars are detailed in Appendix 12. Cost estimates for railroad track modification and extension at KSC and APCI for eighteen railcars are also detailed in Appendix 12. For this option, a 2/3 prorata share of the KSC Design Engineering (DE) cost estimate is used for ten railcars. Estimated investment cost for this option follows.

- Equipment Investment Cost

	1977 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
Seven 34,000-Gal Railcars	$2,100,000	$2,752,700

- Cost Adjustment Factor (10 Percent) — $ 275,300

- Four 34,000-Gal Railcars (Rehabilitated) — $ 52,000

- Facility Construction Cost

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
KSC Track Modifications and Extensions	$1,779,300	
APCI Track Extensions	165,300	
APCI Piping and Transfer Lines	794,100	
	$2,738,700	$4,436,700

- Design Fee (6 Percent) — 266,200

Total Investment Cost — $7,782,900

3.0 OPERATING COST

Operating cost associated with this option includes the cost of transporting LH_2 requirements by 13,000-gal mobile tanker (using common carrier tractors), APCI Terminal and Administration (T&A) charges, and the cost of the trackmobile and 34,000-gal LH_2 railcar delivery. The estimated cost for common carrier delivery is based on NASA8-31034 contract prices for APCI delivery in 1982 using KSC-owned mobile tankers and is detailed in Appendix E The cost for railcar round trip delivery, T&A costs, and trackmobile operations are detailed in Appendix 12. Railcar costs include switching and

and rebate considerations. Operating cost factors and the estimated operating cost for this option follow.

- Operating Cost Factors

  Assets: Seven 13,000-Gal Tankers

  Ten 34,000-Gal Railcars

  Common Carrier Delivery . . . . . . $1.12/Mile (1982 Dollars)

  Railcar Round Trip Cost . . . . $2,157 (1977 Dollars)

- Common Carrier Cost (20 Mobile Tanker Loads/Launch)

YEAR	COST/MILE	MILES	ROUND TRIPS	COST/YEAR F.O.B. ORIGIN
1982	$1.12	1,386	260	$ 403,603
83	1.20	1,386	720	1,197,504
84	1.28	1,386	800	1,419,264
--	--	--	--	--
1991	2.06	1,386	800	2,284,128
		Common Carrier Cost		$16,181,700

- Railcar Operating Cost (10 Operational Railcars)

YEAR	LAUNCHES	COST RAILCAR ROUND TRIP	RAILCAR TRIPS	COST/YEAR
1982	13	$3,025	130	$ 393,250
83	36	3,237	360	1,165,320
84	40	3,463	400	1,385,300
--	--	--	--	--
1991	40	5,561	400	2,224,400
		Railcar Operating Cost		$15,769,800

- APCI T&A Charges (Appendix 6) $ 665,500

- Trackmobile Cost (Appendix 12) $ 78,800

Total Operating Cost $32,695,800

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes mobile tanker maintenance cost, LH_2 railcar maintenance costs, trackmobile maintenance cost, and KSC Administration and Scheduling (A&S) cost. Based upon KSC maintenance records and current APCI refurbishing price quotations, the 1982 maintenance cost for each 13,000-gal mobile tanker plus A&S costs for clerical salary and maintaining administrative records of mobile tanker operations at KSC by contractor personnel, are detailed in Appendix 6. Maintenance cost factors for LH_2 railcars and the KSC trackmobile are detailed in Appendix 2. Estimated total maintenance cost for this option follows.

- Railcar Maintenance Cost (Appendix 2)

YEAR	MAINTENANCE COST/ RAILCAR	CARS IN SERVICE	COST/YEAR
1982	$4,067	11	$ 44,737
83	4,352	11	47,872
84	4,656	11	51,216
--	--	--	--
1991	7,478	11	82,258
	Railcar Maintenance Cost		$618,800

- <u>Trackmobile Maintenance Cost (Appendix 2)</u> $ 41,000

- <u>Mobile Tanker Maintenance Plus A&S Cost (Appendix 6)</u> $1,434,100

<u>Total Maintenance Cost</u> $2,093,900

5.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), and trackmobile operator functions. As in Appendix 2, trackmobile operators are included in the operation cost. With simultaneous offloading of two railcars at 2 hours per offloading operation, the total offloading time for the ten railcars should average about 5 hours under this option. The 13,000-gal mobile tankers will arrive for offloading in six sets of four mobile tankers and three mobile tankers as indicated in the traffic model in Figure 15-1. At 2 hours per operation, total offloading time for mobile tankers should average 12 hours under this option. Fire and Safety personnel are required in each area 1/2 hour prior to and following offloading operations. VO personnel are required in each area 1 hour prior to and following offloading operations to establish security, prepare the sites for operation, and shut down the sites following operations. Estimated cost factors and total offloading costs for this combined assets option follow.

- Cost per Combined Offloading Operation ($19.51/Hour 1982 Dollars)

FUNCTION	PERSONNEL	HOURS/ OPERATION	TOTAL MAN-HOURS	COST/TRANSFER
Safety	1	18	18	$ 351
Fire	4	18	72	1,404
VO	3	19	57	1,112
	Cost per 18-Railcar Transfer			$2,867

- Combined Offloading Cost

YEAR	COST/TRANSFER	NUMBER OF CYCLES	COST/YEAR
1982	$2,867	13	$ 37,271
83	3,067	36	110,412
84	3,282	40	131,280
--	--	--	--
1991	5,271	40	210,840
	Total Offloading Cost		$1,494,200

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of this option is increased significantly. For example, at 20 launches per year, investment cost could be eliminated and maintenance costs could be reduced approximately 20 percent. In addition, an estimated 50-percent reduction in operating and a 23-percent reduction in offloading costs could be achieved. Transfer/efficiency losses could also be reduced by 50 percent except boiloff losses which would continue at a uniform rate. Estimated total cost, by category, for this option at 20 STS launches per year follows.

Investment Cost	None
Operating Cost	$16,826,600
Maintenance Cost	1,700,100
Offloading Cost	1,164,500
Transfer/Efficiency Cost	6,700,000
TOTAL COST (20 LAUNCHES/YEAR)	$26,391,200

APPENDIX 16

APPENDIX 16

OPTION 16 - COMBINED ASSETS - MOBILE TANKERS

1.0 CONCEPT OF OPERATION

Option 16 is based on the use of the seven existing KSC-owned 13,000-gal mobile LH_2 tankers and the four existing NASA-owned 34,000-gal LH_2 railcars at Lewis Research Center combined with four 19,700-gal LH_2 mobile tankers to support 40 STS launches per year. Five additional mobile tankers of 19,700-gal capacity (four operational and one maintenance spare) would be procured incrementally as needed. The seven 13,000-gal and four 19,700-gal mobile tankers would be transported by common carrier tractors on a 56-hour round trip schedule as in Option .. The four 34,000-gal railcars would be transported by scheduled rail carrier on a 9-day round trip basis as in Option 12.

To provide 500,000 gal of LH_2 per launch and to provide for transfer/efficiency losses, a total of 560,000 gal of LH_2 would be loaded in KSC mobile tankers and railcars at APCI. Delivery of LH_2 directly into storage spheres at Pads A and B would be accomplished during days 1 through 7 by mobile tankers and on a specified day of the launch cycle for railcars with no deliveries on the day preceeding the (or on the actual) launch date.

The combined mobile tanker and railcar assets would operate as four separate transportation elements. The first element would consist of four 13,000-gal mobile tankers, the second would consist of four 19,700-gal mobile tankers, the third would consist of four 34,000-

gal railcars, and the fourth element would consist of three 13,000-gal mobile tankers.

Under this option, each 13,000-gal LH_2 tanker would be loaded with 11,700 gal of LH_2 by APCI (assuming 6-percent ullage and a 6-percent water density safety fill factor). Depressurization, boiloff, and other transfer losses would amount to approximately 1,025 gal. Each mobile tanker would then deliver approximately 10,500 gal of LH_2 into the KSC storage spheres each round trip. Loadout at APCI for each of the 34,000-gal railcars would be 31,700 gal of LH_2 (allowing 6-percent ullage and a 6-percent water density safety factor). Depressurization, boiloff, and other transfer losses would amount to approximately 2,600 gal. Each railcar would then deliver 29,000 gal of LH_2 into the storage spheres at Pads A and B as required. Loadout at APCI for each of the 19,700-gal mobile tankers would be 17,600 gal of LH_2 (allowing for a 6-percent ullage and a 6-percent water density safety factor). Depressurization and other transfer losses would amount to approximately 1,540 gal, allowing about 16,000 gal of LH_2 to be placed in storage each round trip.

The proposed launch cycle would begin with each pad storage sphere containing 850,000 gal of LH_2. When a launch occurs from Pad A, storage in Sphere A would be reduced to 350,000 gal. Beginning the day following launch, and continuing for the next 7 days, nineteen 13,000-gal and twelve 19,700-gal mobile tanker loads and four 34,000-gal railcar loads of LH_2 would arrive at Pad A until storage levels are returned to 850,000 gal. This same procedure would be repeated for each launch at Pad B. Traffic models for each method of transportation are shown in Figures 6-1, 8-2 and 12-5. APCI mobile tankers with delivery f.o.b. KSC could be used to provide backup support in the event of accident or maintenance delays, or the additional 16,000-gal KSC LH_2 tanker could be used for this purpose if required.

2.0 INVESTMENT COST

Estimated investment cost to support this option consists of the purchase of five new 19,700-gal LH_2 mobile tankers, refurbishing the four existing NASA-34,000-gal railcars, and expansion of the KSC LH_2 mobile tanker parking/maintenance pad to accommodate twelve tankers and two rechargers. The seven existing KSC-owned 13,000-gal mobile tankers and the four NASA-owned 34,000-gal railcars at Lewish Research Center are assumed to be available and serviceable in 1982. As common carrier tractors are used with this option, no additional equipment is required. Cost estimates for procuring new 19,700-gal tankers are detailed in Appendix 8. Cost estimates for refurbishing the NASA-owned 34,000-gal railcars are detailed in Appendix 2. Cost estimates for expanding the LH_2 mobile tanker hardstand are prorated from the estimate in Appendix 6. Projected investment cost to the time contracts would be awarded follows.

- Equipment Investment Cost

	1977 VENDOR ESTIMATE	1981 BUDGET ESTIMATE
Five 19,700-Gal Mobile Tankers	$2,500,000	$3,276,900

- Cost Adjustment Factor (10 Percent) — $ 327,700

- Four 34,000-Gal Railcars (Rehabilitated) — $ 40,000 — $ 52,000

- Facility Construction Cost

	1977 ENGINEERING ESTIMATE (E)	1981 BUDGET ESTIMATE (1.62E)
Mobile Tanker Maintenance Hardstand	$ 35,000	$ 56,700

- Design Fee (6 Percent) — 3,400

Total Investment Cost — $3,664,700

3.0 OPERATING COST

Operating cost associated with this option includes the cost of transporting LH_2 requirements by 13,000-gal and 19,700-gal mobile tankers (using common carrier tractors), APCI Terminal and Administration (T&A) charges, delivery costs by 34,000-gal railcar and trackmobile costs. The estimated cost for common carrier delivery is based on NAS8-31034 contract prices for APCI delivery in 1982 and is detailed in Appendix 6. Railcar round trip cost is based on current Florida East Coast (FEC) Railroad price quotations and is detailed in Appendix 12. Operating cost factors and the estimated operating cost for the period 1982 through 1991 follows.

- Operating Cost Factors

Assets: Seven 13,000-Gal Tankers @ 19 Round Trips/Launch

Five 19,700-Gal Tankers @ 12 Round Trips/Launch

Four 34,000-Gal Railcars @ 1 Round Trip/Launch

Common Carrier Delivery $1.12/Mile (1982)

Railcar Round Trip Cost $2,157 (1977)

Trackmobile Cost (1/3 X Appendix 2) $26,300

- Operating Cost (13,000- and 19,700-Gal Mobile Tankers)

YEAR	ROUND TRIPS/ YEAR	MILES	COST/MILE COMMON CARRIER	COST/YEAR
1982	403	1,386	$1.12	$ 625,585
83	1,116	1,386	1.20	1,856,130
84	1,240	1,386	1.28	2,199,858
--	--	--	--	--
1991	1,240	1,386	2.06	3,540,397
	Mobile Tanker Operating Cost			$25,081,800

- Railcar Operating Cost

YEAR	ROUND TRIPS/ YEAR	COST/ ROUND TRIP	COST/YEAR
1982	52	$3,025	$ 157,300
83	146	3,237	472,602
84	160	3,463	554,080
--	--	--	--
1991	160	5,561	889,760
	Railcar Operating Cost		$6,315,000

- APCI T&A Cost (Appendix 6) $ 665,500

- KSC Trackmobile Cost (1/3 X Appendix 2) $ 26,300

Total Operating Cost $32,088,600

4.0 MAINTENANCE COST

Maintenance cost associated with this option includes 13,000- and 19,700-gal mobile tanker maintenance costs, KSC Administr ... Scheduling (A&S) costs, 34,000-gal railcar maintenance costs, and KSC trackmobile maintenance costs. Maintenance cost for all mobile tankers is assumed to be equal and is detailed in Appendix 6. Maintenance costs for the 34,000-gal railcars are detailed in Appendix 12 and maintenance costs for the KSC trackmobile are detailed in Appendix 2. A&S costs are standard and are detailed in Appendix 6. Estimated maintenance cost for the combined assets of this option follow.

- Mobile Tanker Maintenance Cost

YEAR	COST/ TANKER/YEAR	TANKERS IN SERVICE	COST/YEAR
1982	$4,780	12	$ 57,360
83	5,115	12	61,375
84	5,473	12	65,671
--	--	--	--
1991	8,788	12	105,456
	Mobile Tanker Maintenance Cost		$792,500

- Mobile Tanker Tire and Brake Cost (Appendix 6) $1,154,800

- Railcar Maintenance Cost

YEAR	COST/RAILCAR	RAILCARS IN SERVICE	COST/YEAR
1982	$4,067	4	$ 16,268
83	4,353	4	17,408
84	4,656	4	18,624
--	--	-	--
1991	7,478	4	29,910
	Railcar Maintenance Cost		$ 225,000

- KSC A&S Cost (Appendix 6) $ 221,900

- Trackmobile Maintenance Cost (Appendix 2) $ 41,000

Total Maintenance Cost $2,435,200

ɔ.0 OFFLOADING COST

Offloading operations for this option include Safety, Fire, Vehicle Operations (VO), mobile tanker operator, and trackmobile operator functions. Common carrier drivers will perform mobile tanker operator functions and trackmobile operators are included in the operating cost as in Appendix 2. Thirty-one mobile tanker loads of LH_2 are required each launch cycle. For offloading purposes, these mobile tankers will arrive in nine sets of up to four tankers each. The first set of four mobile tankers will arrive at KSC on the morning following an STS launch. The remaining eight sets of mobile tankers will arrive as indicated on the traffic diagram (Figure 16-1). Nine separate offloading operations for mobile tankers would be required at 2 hours [illegible] on.

The four railcars would be offloaded in groups of two on the 2-inch offload manifold with an offloading time of 2 hours per operation. Total offloading cost factors and cost for this option follow.

- Cost per Combined Offloading Operation per Launch (11 Operations)

FUNCTION	PERSONNEL	HOURS OPERATION	TOTAL MAN-HOURS	COST AT $19.51/ MAN-HOUR (1982)
Safety	1	3	33	643
Fire	4	3	132	2,575
VO	3	4	132	2,575
	Offloading Cost/Launch			$5,793

- Combined Offloading Cost

YEAR	NUMBER OF CYCLES	COST/TRANSFER	COST/YEAR
1982	13	$ 5,793	$ 75,309
83	36	6,199	223,164
84	40	6,633	265,320
--	--	--	--
1991	40	10,643	425,720
		Total Offloading Cost	$3,020,500

6.0 REDUCED LAUNCH RATE SENSITIVITY

For an STS launch frequency of less than 40 launches per year, the cost-effectiveness of Option 16 remains high. In terms of operations, offloading, and transfer/efficiency costs, the most efficient method is to procure and use five 19,700-gal mobile LH_2 tankers with common carrier delivery in conjunction with the four NASA-owned 34,000-gal railcars. Although the use of 13,000-gal mobile tankers would reduce the initial investment, this cost is less than the saving in operating, offloading, and maintenance costs achieved with the larger tanker. Under this option, investment cost would include the cost of five 19,700-gal mobile tankers and rehabilitation of the four NASA-owned 34,000-gal railcars. Operating cost could be reduced 60 percent, offloading costs could be reduced approximately 50 percent and maintenance costs could be reduced approximately 20 percent. Transfer/efficiency losses could be reduced approximately 50 percent if no "heel" is retained after offloading operations at KSC. Estimated costs at 20 STS launches per year follow.

Investment Cost	$ 3,656,600
Operating Cost	16,044,300
Maintenance Cost	1,948,200
Offloading Cost	1,510,500
Transfer/Efficiency Cost	6,700,000
TOTAL COST (20 LAUNCHES/YEAR)	$29,859,600

APPENDIX 17

APPENDIX 17

LH_2 TRANSFER/EFFICIENCY LOSSES

1.0 GENERAL

This appendix is a compilation of overall LH_2 losses for each of the options addressed in this study. Total program losses for each option are based on an estimated LH_2 average price of $1.28 per pound during the period 1982 through 1991.

METHOD	GALS/LAUNCH						COST PER LAUNCH	TOTAL PROGRAM COST (x $1000)
	DEPRESSURI-ZATION LOSSES	TRANSFER LINE COOLDOWN LOSSES	HEAT LEAK LOSSES	LINE RESIDUAL LOSSES	BOILOFF LOSSES	TOTAL LOSSES		
1. BARGE TO PADS A & B	21,105	1,660	146	2,552	11,497	36,960	28,002	10,333
2. BARGE WITH RAILCAR	36,857	11,255	300	2,570	11,497	62,479	47,336	17,467
3. BARGE WITH PIPELINE	21,105	13,180	1,930	4,160	11,497	51,872	39,300	14,502
4. BARGE WITH TANKERS	37,475	11,255	300	2,570	11,497	63,097	47,804	17,640
5. BARGE WITH INVENTORY TANK	43,285	15,170	335	3,500	17,652	79,942	60,567	22,349
6. 13,000-GAL TANKER - COMMON CARRIER	32,741	1,530	300	1,380	14,310	50,261	37,957	14,006
7. 13,000-GAL TANKER - GOVERNMENT TRUCKS	32,741	1,530	300	1,380	14,310	50,261	37,957	14,006
8. 19,700-GAL TANKER - COMMON CARRIER	32,453	1,530	300	920	14,184	49,383	37,294	13,762
9. 19,700-GAL TANKER - GOVERNMENT TRUCKS	32,453	1,530	300	920	14,184	49,383	37,294	13,762
10. 13,000-GAL TANKER - F.O.B. PADS	32,741	1,530	300	1,380	14,310	50,261	37,957	14,006
11. 13,000-GAL TANKER - F.O.B. INVENTORY TANKS	54,921	3,065	300	2,760	18,915	79,961	60,386	22,283
12. 34,000-GAL RAILCARS	31,505	762	300	195	13,950	46,712	35,276	13,017
13. SPECIAL TRAIN (18 Car)	31,505	762	300	195	9,180	41,942	31,675	11,688
14. SPECIAL TRAIN (36 Car)	31,505	762	300	390	10,710	43,667	32,977	12,169
15. COMBINED ASSETS - RAILCARS	32,019	1,004	300	690	13,750	47,763	36,070	13,310
16. COMBINED ASSETS - TANKERS	32,453	1,288	300	805	14,100	48,946	36,964	13,640

FIGURE 17-1
TRANSFER/EFFICIENCY LOSSES

APPENDIX 18

APPENDIX 18

FUEL CONSUMPTION

1.0 GENERAL

A comparison of diesel fuel consumption for each method of LH_2 transportation used in this study for the period 1982 through 1991 is shown in Figure 18-1. A comparison of the relative fuel cost escalated at the uniform rate of 7 percent per year and at the rate of 14 percent per year during the same period is shown in Figures 18-2 and 18-3.

2.0 FUEL CONSUMPTION

In developing the fuel consumption and fuel cost tables used in this appendix, the following data were used. Fuel costs were escalated from a 1977 base cost of $0.40 per gal.

TRANSPORTATION METHOD	FUEL CONSUMPTION
Tractor With 13,000-Gal Tanker	4.50 Miles/Gal
Tractor With 19,700-Gal Tanker	4.00 Miles/Gal
Locomotive (2,000-HP*) With 18 Railcars	.50 Miles/Gal
Locomotives (Two 200 HP) With 36 Railcars	.33 Miles/Gal
Seagoing Tug (2,000 HP)	45.00 Gal/Hour

3.0 DISTANCE FACTORS

In developing the fuel consumption and cost factors used in this study, the following distance and time factors were used.

* Horsepower

TRANSPORTATION METHOD	ROUND TRIP DISTANCE/TIME
Truck Tractors	1,386 Miles
Locomotives	1,500 Miles
Barge*	230 Hours

* Average barge speed = 8 Miles per hour

FUEL CONSUMED (GAL)

LH_2 TRANSPORTATION METHODS

YEAR	TRUCK WITH 13,000-GAL TANKER	TRUCK WITH 19,700-GAL TANKER	TRAIN - 18 RAILCARS	TRAIN - 36 RAILCARS	SEAGOING TUG
1982	192,192	144,352	39,000	29,250	100,906
83	532,224	399,744	108,000	81,000	279,432
84	591,360	444,160	120,000	90,000	310,480
85	591,360	444,160	120,000	90,000	310,480
86	591,360	444,160	120,000	90,000	310,480
87	591,360	444,160	120,000	90,000	310,480
88	591,360	444,160	120,000	90,000	310,480
89	591,360	444,160	120,000	90,000	310,480
90	591,360	444,160	120,000	90,000	310,480
1991	591,360	444,160	120,000	90,000	310,480
Total	5,455,296	4,097,376	1,107,000	830,250	2,864,178

FIGURE 18-1

DIESEL FUEL CONSUMPTION

1982 THROUGH 1991

FUEL COST - 7-PERCENT ESCALATION

LH_2 TRANSPORTATION METHODS

YEAR	TRUCK WITH 13,000-GAL TANKER	TRUCK WITH 19,700-GAL TANKER	TRAIN - 18 RAILCARS	TRAIN - 36 RAILCARS	SEAGOING TUG
1982	$ 108,396	$ 81,289	$ 21,196	$ 16,497	$ 56,914
83	321,179	240,865	65,175	48,881	168,631
84	381,847	286,362	77,486	58,115	200,484
85	408,576	306,407	82,910	62,183	214,518
86	437,176	327,856	88,714	66,536	229,534
87	467,779	350,806	94,924	71,193	245,601
88	500,523	375,362	101,569	76,177	262,793
89	535,560	401,638	108,679	81,509	281,189
90	573,049	429,752	116,286	87,215	300,872
1991	613,162	459,835	124,426	93,320	321,933
Total	$4,347,247	$3,260,172	$881,365	$661,626	$2,290,469

FIGURE 18-2

DIESEL FUEL COST

1982 THROUGH 1991

FUEL COST - 14-PERCENT ESCALATION

LH_2 TRANSPORTATION METHODS

YEAR	TRUCK WITH 13,000-GAL TANKER	TRUCK WITH 19,700-GAL TANKER	TRAIN - 18 RAILCARS	TRAIN - 36 RAILCARS	SEAGOING TUG
1982	$ 108,396	$ 81,414	$ 21,996	$ 16,497	$ 56,910
83	342,220	257,035	69,444	52,083	179,674
84	433,466	325,569	87,960	65,970	227,581
85	494,151	371,148	100,274	75,205	259,443
86	563,332	423,109	114,312	85,734	295,764
87	642,198	482,345	130,316	97,737	337,171
88	732,106	549,873	148,560	111,420	384,375
89	834,601	626,855	169,359	127,019	438,187
90	951,446	714,615	193,069	144,802	499,534
1991	1,084,648	814,661	220,099	165,074	569,468
	$6,186,564	$4,646,624	$1,255,389	$941,541	$3,259,500

FIGURE 18-3

DIESEL FUEL COST

1982 THROUGH 1991