MER-1374A

SOLID ROCKET PROPELLANT WASTE DISPOSAL/INGREDIENT RECOVERY STUDY

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FINAL REPORT
JPL CONTRACT 954161A

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Thiokol / WASATCH DIVISION

A DIVISION OF THIOKOL CORPORATION

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FINAL REPORT

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I. INTRODUCTION AND SUMMARY

There exists the technological feasibility, economic and energy conservation incentives, as well as the ecological appeal, to recover ingredients from waste propellant. The presence of a large amount of uniform composition waste propellant lends itself to the design and construction of a plant to recover ingredients in a volume great enough to pay out the investment, as well as eliminate the open burning of waste propellant.

This study was initiated by the Jet Propulsion Laboratory (JPL) with the aim of better definition of the economic and energy related aspects of waste rocket propellant disposal. This document constitutes the final report as required by the JPL contract.

Environmental and economic pressures are building toward the elimination of open burning as a viable method of waste propellant disposal. The selection, development and implementation of an acceptable alternate is of vital concern. The intelligent selection of the right method is dependent, at least in part, on the economic and energy impact.

A comparison of facility and operating costs of the alternate methods shows open burning to be the lowest cost incineration method of waste propellant disposal.

The recovery of ingredients from waste propellant has the probability of being able to pay its way, and even show a profit, when large consistent quantities of composite propellant are available. Ingredients recovered from Space Shuttle waste propellant would be worth over $1.5 millions.

Open burning and controlled burning are both energy wasteful.

Ingredient recovery could conserve 100 million kwh of energy on the Space Shuttle program.

II. COST EVALUATIONS OF WASTE PROPELLANT DISPOSAL METHODS

A. OPEN BURNING METHOD

In the determination of the costs involved in open burning of waste propellant, use was made of information available at Thiokol.

The replacement cost of an existing burning area has been defined as follows:

	Capital
Land acquisition (820 acres at $300 per acre)	$246,000
Containment fence (4,700 ft lineal length)	3,000
Control bunker	30,000
Safe ignition system	8,000
Igniter storage area	2,000
Propellant storage area	4,000
Roads and lights	20,000
Debris pit	5,000
TOTAL	$318,000

The operational manhours per year for one year is:

	Manhours Per Year
Packaging	300
Collection, transportation, and storage	5,000
Actual burning	300
Postburn cleanup	800
TOTAL	6,400

At a labor rate of $12 per hour, these manhours translate to a cost of $76,800 per year. With the addition of material (such as igniters, gloves, containers, etc.) costs of $1,250 per year and truck rental costs of $3,000 per year, the total operating cost for an open burning facility amounts to $81,050 per year.

The actual operating cost per pound of propellant burned has been calculated for the last three years as follows:

	Cents Per Pound
1973	2.1
1974	4.3
1975	2.1

In contrast to this relatively low cost per pound, one propellant producer in California pays $1.00 per pound to have his propellant packaged, transported, and burned. The main reasons for this difference are the restrictions placed on open burning in California and the small quantities of propellant involved.

B. CONTROLLED BURNING WITH COMBUSTION GAS CLEANUP METHOD

This is a complex area in which to pin down costs. The Army, Navy, and Air Force are all involved in various methods of controlled burning with combustion gas cleanup.

The Army at Picatinny Arsenal[1] is working with pilot plant operation of induced draft, rotary kiln, and fluosolid incinerators. Their pilot plant capacity is in the 250 pounds per hour range. They plan conversion of an induced draft furnace to a 1,350 pounds per hour fluosolid incinerator.

The propellant (or explosive) washed out of the rocket motor is shredded under a water stream and transported as a slurry to the various incinerators. All but the fluosolid incinerator (which requires a cyclone separator to remove the particulate matter) require scrubbing of combustion gases. No capital or operating costs are available at this time.

[1]"Incineration Processes for Propellant and Explosive Waste Disposal;" Joseph S. Santos and John J. Canavan; Facilities and Protective Technology Division, Manufacturing Technology Directorate, Picatinny Arsenal

The Navy at Indian Head, Maryland[1] is in the process of developing a motor reclamation and propellant disposal complex. A concept sketch of the complex is shown in Figure 1. The propellant washed out of a rocket motor is shredded with water and the resultant slurry fed to a wet oxidation reactor system which operates at 450° F and 600 psi.

The reported capital cost of the entire complex is $20,000,000.

The high pressure wet oxidation unit, shown in Figure 1, which would have the capacity of 5 tons per day (417 pounds per hour), is estimated to cost $800,000 to build. The labor and maintenance costs for the wet oxidation reactor are estimated at $15 per ton or 0.75 cents per pound.

The Air Force at Edwards, California, has under construction a facility for incineration of solid and liquid propellants. A rotary kiln is used for the solid propellant and a special burner is used for the liquid oxidizers and fuels. All combustion gases are scrubbed. The design capacity is 500 pounds per hour of solid propellant and 600 pounds per hour of liquid propellant. The capital cost was reported as approximately $3,000,000. The operating cost has not been determined, therefore, the cost per pound has not yet been calculated.

C. INGREDIENT RECOVERY METHOD

1. Capital Costs

The cost of an Ammonium Perchlorate (AP) recovery plant is estimated to be $250,000. This would be a portable plant (shown in Figure 2) with the capability of processing 21,000 pounds per day (or 875 pounds per hour) of composite propellant. It would produce 13,965 pounds per day of pure and damp ammonium perchlorate.

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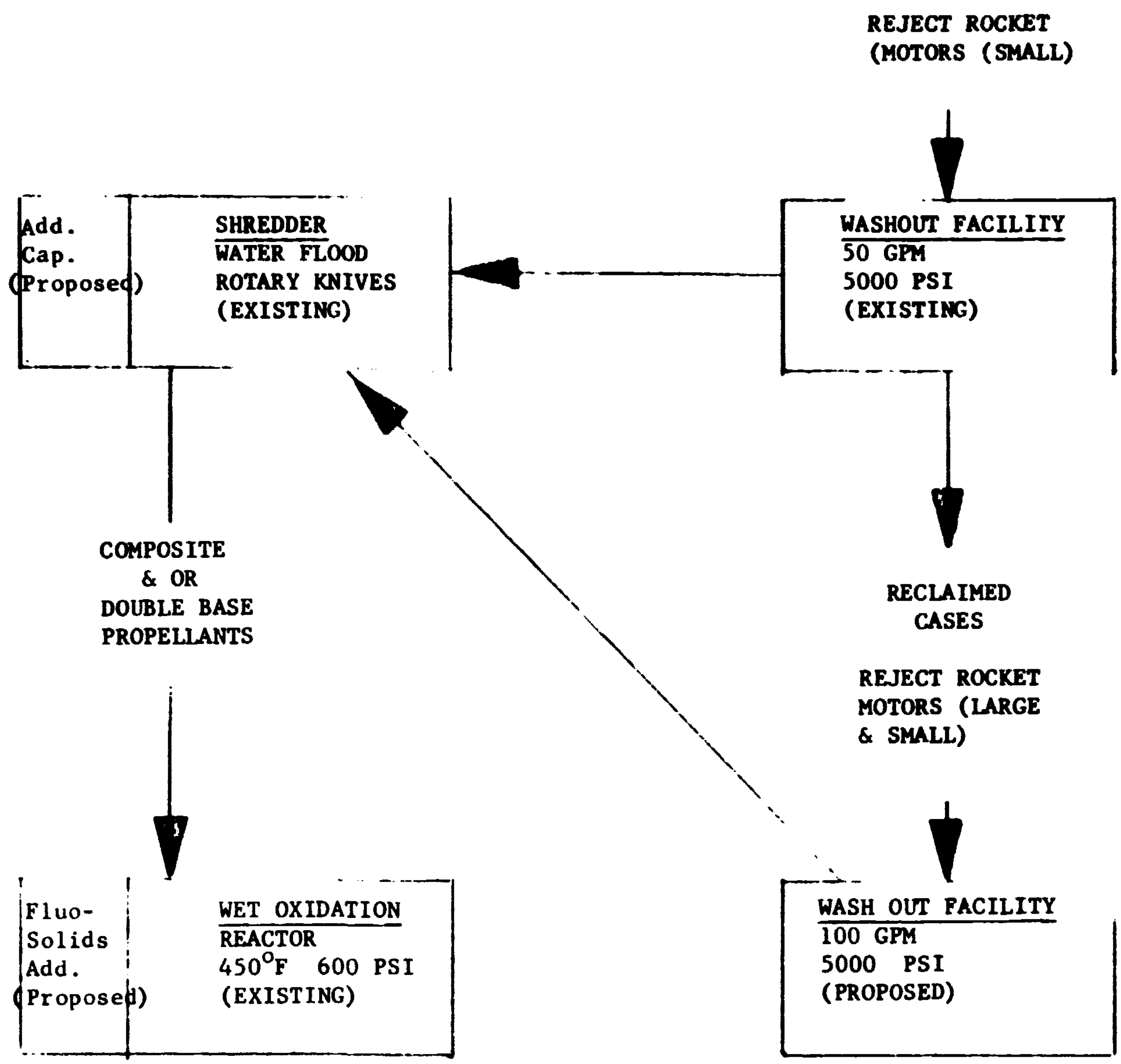
[1] Indian Head Memorandum Report 73-240; "Industrial Preparedness Measure: Propellant Disposal/Reclamation Facility Design." Naval Ordnance Station, Indian Head, Maryland



COST ESTIMATE FOR COMPLETE COMPLEX - $20,000,000

COMPLETION ESTIMATE - 3 TO 5 YEARS

Figure 1. Navy Demilitarization Facility at Indian Head, Maryland

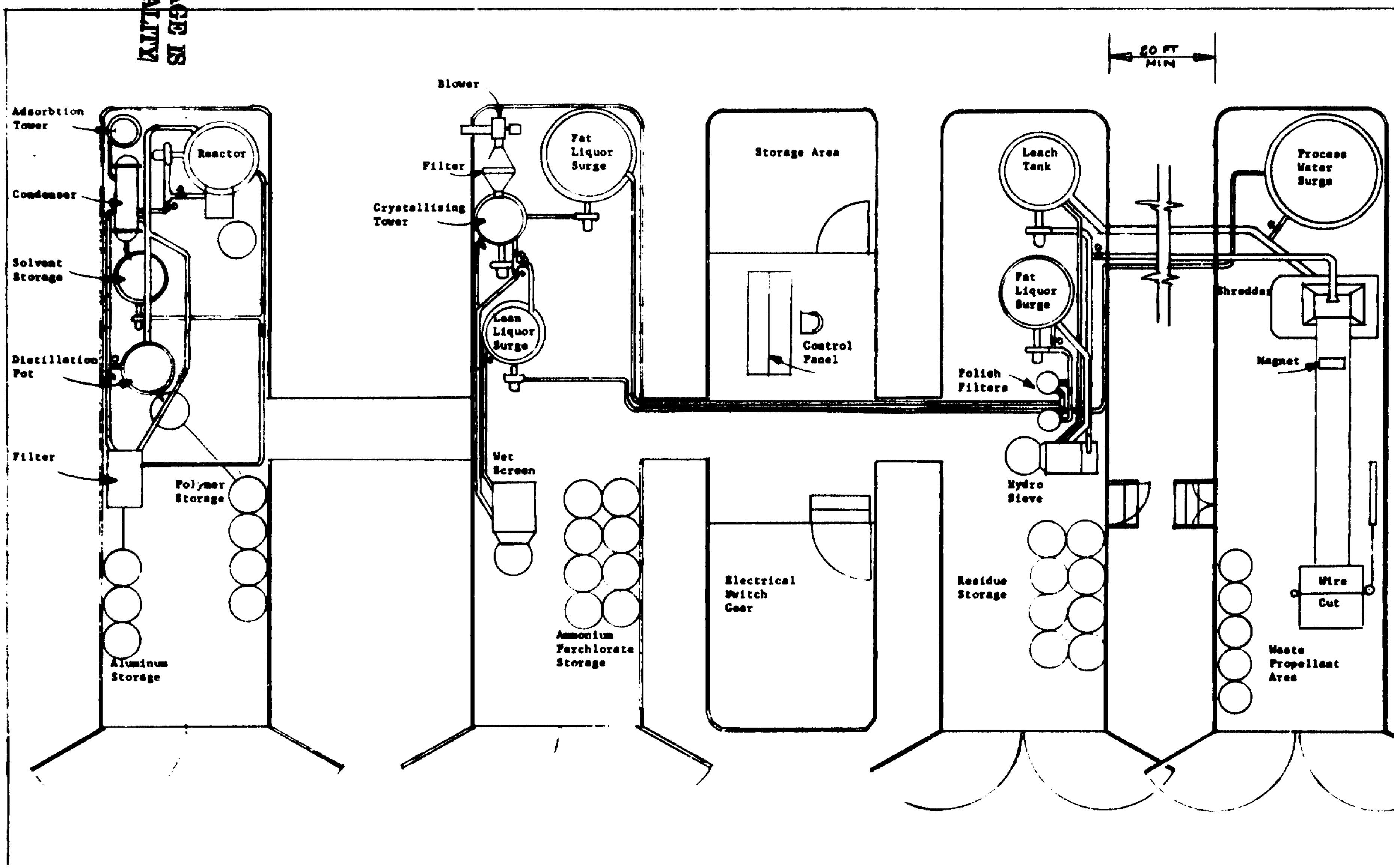


Figure 2. Waste Propellant Ingredient Recovery System Concept (Portable)

For an additional $60,000, an air oxidation equipped trailer can be added to recover the aluminum powder from the residues left from the AP recovery plant. At the high propellant rate of 21,000 pounds per day, 3,360 pounds per day of high quality aluminum could be produced. As an alternate, a $75,000 transesterification-equipped trailer could be used to recover both 3,360 pounds per day of high-quality aluminum and 2,940 pounds per day of impure polymer.

2. Operating Costs

In calculating the operating costs of an ammonium perchlorate recovery plant, the following assumptions were made:

1. 21,000 pounds of waste propellant are processed in 24 hours (7,000 pounds per shift).
2. The propellant will contain 70 percent ammonium perchlorate; 95 percent of the AP is recovered.
3. 20 percent downtime will be experienced.
4. 13,965 pounds of ammonium perchlorate will be recovered each day (4,655 pounds per shift).
5. One operator and one helper would be required to operate the plant.
6. Program support would require two manhours per day.
7. Laboratory support would require five manhours per day.
8. Utility costs will be $20.00 per day.
9. Transportation costs of ammonium perchlorate in Econ-O-Bin containers to Henderson, Nevada (allowing for 10 percent moisture) are 1.635 cents per pound.

3. <u>Operating Cost Calculations</u>

a. Ammonium Perchlorate Recovery

	Costs Per Day
Labor Support (48 manhours x $17.71/hour)	$ 850.08 (Direct-Direct)
Laboratory Support (5 manhours x $19.65/hour)	98.25 (Direct-Direct)
Program Support (2 manhours x $24.53/hour)	49.06 (Direct-Direct)
Daily Labor	$ 997.39 (Direct-Direct)
Daily Utility Costs	20.00
Total Daily Production Costs	$1,017.39
Average Daily Freight Costs (Brigham City, Utah to Henderson, Nevada)	228.33
TOTAL	$1,245.72

The resale value at Henderson, Nevada will be at least 16 cents per pound.

Savings are 16 cents per pound minus 8.92 cents per pound = 7.08 cents per pound. The expected waste propellant and oxidizer from Space Shuttle and other programs projected from 1976 to 1989 will amount to 7,962,600 pounds of propellant and 2,800,000 pounds of scrap ammonium perchlorate. This expected waste represents 8,095,129 pounds of recoverable ammonium perchlorate. At 7.08 cents per pound, this would amount to $573,135 savings on recovered ammonium perchlorate alone during the 1976 to 1989 time period.

b. Aluminum Recovery

In calculating the operating cost of an aluminum recovery (air oxidation) or an aluminum and polymer recovery (transesterification) trailer addition, the following assumptions were made:

1. The aluminum and polymer recovery trailer will be conveniently located close to the AP recovery trailers to allow monitoring of the operation,

addition of residue, as well as aluminum powder and polymer removal by operators from the AP recovery trailers.

2. Instruments will be installed that will allow monitoring from the AP recovery trailer control room.

3. The daily residue after the AP is removed will contain 3,360 pounds of aluminum and 2,940 pounds (350 gallons) of impure polymer.

4. Utilities and materials will cost $30 per day.

5. Aluminum powders and impure polymer will be loaded in used barrels available on plant.

6. The value of aluminum powder is 40 cents per pound from the air oxidation process and 75 cents per pound from the transesterification process.

7. The impure polymer will have a value of 23.6 cents per gallon (or 2.83 cents per pound) as a fuel.

1. Air Oxidation Aluminum Recovery

The assumed costs for aluminum recovery using the air oxidation method are:

	Cost
Labor effort covered by AP Recovery Plant	$ 0
Laboratory Support (1 manhour per day average)	19.65 (Direct-Direct)
Program Support (1 manhour per day)	24.53 (Direct-Direct)
Utilities per day	30.00
TOTAL	$74.18

At 3,360 pounds per day of aluminum powder, the cost of process would be 2.2 cents per pound. At a value of 40 cents per pound, the savings would be 37.8 cents per pound.

The quantity of aluminum involved between 1976 and 1989 would amount to 1,274,016 pounds for a 37.8 cents per pound savings. The savings on air oxidation aluminum would amount to $481,578.

2. Transesterification Aluminum and Polymer Recovery

	Costs
Labor effort covered by AP Recovery Plant	$ 0
Laboratory Support (2 manhours per day average)	39.30 (Direct-Direct)
Program Support (2 manhours per day average)	49.06 (Direct-Direct)
Utilities per day	50.00
Makeup alcohol, toluene, and sodium methoxide	5.40
TOTAL	$143.77

At 3,360 pounds per day of aluminum powder, the cost of processing would be 1.28 cents per pound.

At a value of 75 cents per pound for high purity aluminum powder, the savings would be 70.72 cents per pound.

The quantity of aluminum involved between 1976 and 1989 would be 1,274,016 pounds. At 70.72 cents per pound, the total savings on high purity aluminum would be $900,984.

Reclaimed aluminum (even though it meets all of the specifications for use in rocket motors) may still be unsalable for that use. It may be necessary to sell it at a lower price (40 cents per pound). The savings then would be 35.72 cents per pound or for 1,274,016 pounds x 35.72 cents per pound the savings is $455,078 during the 14 year Space Shuttle production period. Selling the 1,115,000 pounds (133,761 gallons) of impure polymer as fuel oil at 23.5 cents per gallon would result in a savings of $31,567 in the 1976 to 1989 time period.

The total savings on AP aluminum and polymer could amount to $1.5 millions over the Space Shuttle production period.

Items that could increase the savings are:

1. Operation of the Recovery Plant with sister division labor and thus reduce labor costs.
2. Negotiate an AP selling price higher than 16 cents per pound.
3. Find a sale for the polymer that would be more lucrative than selling it for fuel.
4. Increase the amount of waste propellant available by washing out recycled motors, such as First Stage Minuteman (45,000 pounds per motor), Third Stage Minuteman motors (7,300 pounds per motor), and even by washing out motors for the Army and Navy.

The AP, aluminum, and polymer available from one First Stage Minuteman mot r would be:

Material	Quantity (lb)	Value ($)	Reclamation Expense ($)	Savings ($)
Ammonium perchlorate	29,925	4,788	2,669	2,119
Aluminum	7,200	2,88C	158	2,721
Polymer	6,300	178	--	178
TOTAL	43,425	7,846	2,827	5,018

The potential savings from one First Stage Minuteman Motor (45,000 lb of propellant) would be $5,000.

Some facility effort would be necessary to prepare the washed out propellant for feeding to the reclamation system.

D. SLURRIED EXPLOSIVES

1. Capital Costs

Slurried explosives are made from shredded propellant or residues (propellant with the ammonium perchlorate removed) mixed with an oxidizer (sodium nitrate or ammonium nitrate), a sensitizer (TNT, PETN or HMX) and a gelling agent.

The facility costs should include a propellant shredder, if one is not available. Assuming that one is not available, the cost for a facility (see Figure 3) to shred, blend, and package slurried explosives at a 50,360 pound per day rate is estimated to be $175,000.

2. Operating Costs

The following assumptions were made:

1. The slurried explosive will contain 41.7 percent shredded propellant, 23.1 percent ammonium nitrate, 5.8 percent sodium nitrate, 14.6 percent PETN (sensitizer), and 0.8 percent gel agent.
2. The quantity of slurried explosives produced will be based on the availability of a maximum of 21,000 pounds of waste propellant per day.

The material costs per day will be:

	Cost Per Day
Ammonium nitrate (4.75 cents per lb for 11,633 lb)	$ 552.57
Sodium nitrate (6.5 cents per lb for 2,921 lb)	189.87
Sensitizer or PETN ($1.00 per lb for 7,353 lb)	7,353.00
Gel agent or gum arabic ($3.00 per lb for 403 lb)	1,209.00
SUBTOTAL	$9,304.44

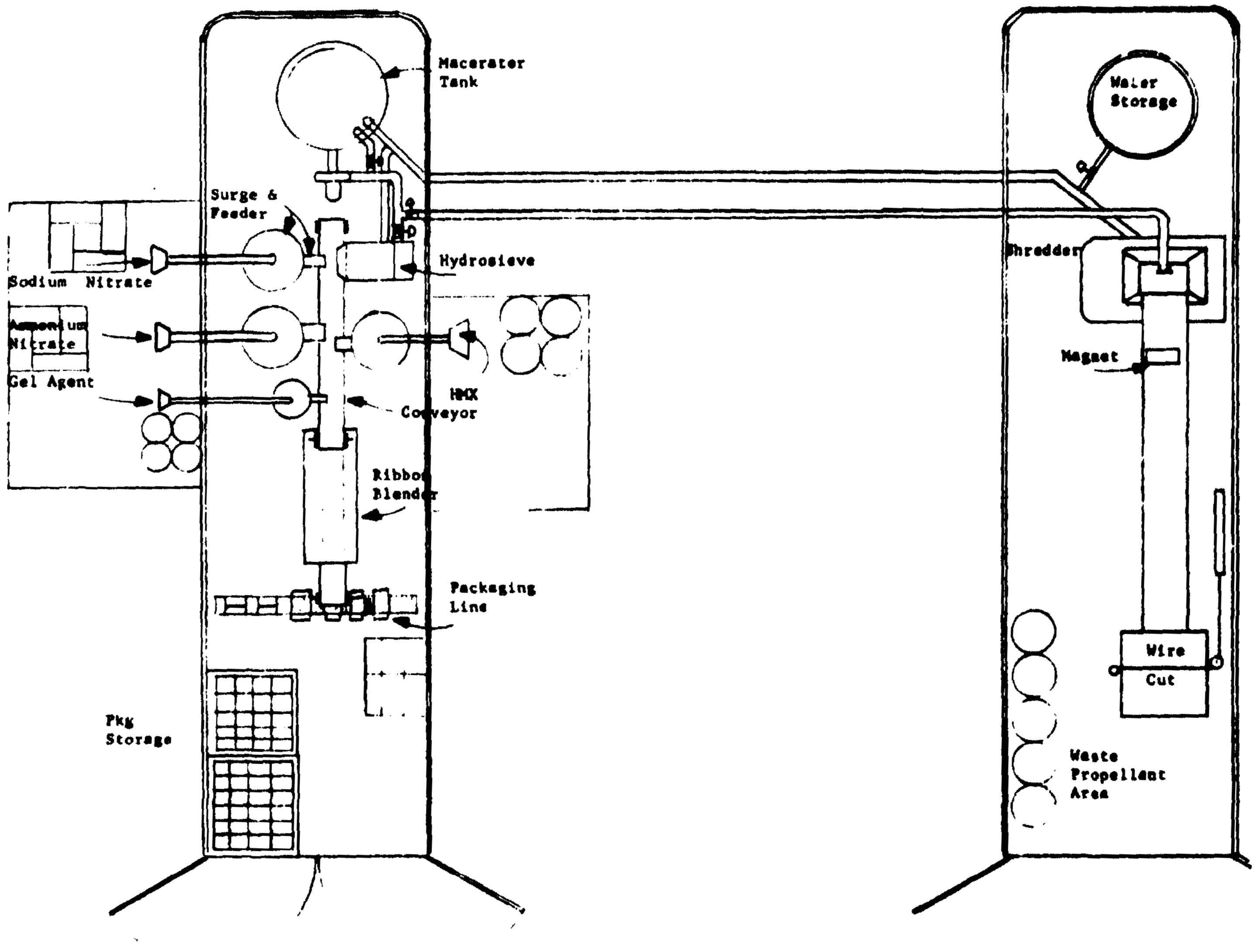


Figure 3. Slurried Explosive Production System Concept (Portable)

	Cost Per Day
Labor (2 operators per shift, 3 shifts per day for 48 manhours x $17.71 per hour)	$ 850.08 (Direct-Direct)
Laboratory Support (2 manhours x $19.65 per hour)	39.30 (Direct-Direct)
Program Support (2 manhours x $24.53 per hour)	49.06 (Direct-Direct)
Daily packaging material costs	300.00
Daily utility costs	20.00
TOTAL	$10,562.88

3. The unit cost for slurried explosive is 21 cents per pound. The sale price is expected to be 40 cents per pound. This would result in a savings of 19 cents per pound or $9,568 per day.

Items that can affect the savings are:

1. The capacity calculated is for the maximum conceivable amount of propellant available. Realistic quantities would be much lower. The daily capacity could be kept up and operating days reduced, or the daily capacity reduced and more operating days utilized. The unit cost will increase if the daily capacity is reduced due to the additional labor required per pound.

2. The substitution of available scrap HMX as a sensitizer would result in a drastic reduction in raw materials cost. The sensitizer (PETN) cost amounts to 79 percent of the cost. If this could be done, the unit cost for slurried propellant would drop to 6.3 cents per pound and the savings would be 33.7 cents per pound or $16,934 per day.

E. DIRECT USE OF PROPELLANT AS FIRE STARTERS

It is expected that a limited quantity (10,000 pounds per year) of waste propellant would be disposed of in the form of fire starters. The Forest Service has shown an interest in these starters. Some of these fire starters have been fabricated and tested successfully inhouse. Twenty units have been fabricated for the Forest Service and it is anticipated that the Forest Service will test them this year. The expected selling price will be $3.25 each.

The cost of producing the 1-gallon fire starters would be:

	Cost Per Shift
Fabrication labor (15 units per manhour; 16 manhours x $17.71)	$283.36 (Direct-Direct)
Transportation labor (15 units per manhour; 2 manhours x $17.71)	35.42 (Direct-Direct)
Program Support (2 manhours x $19.65)	39.30 (Direct-Direct)
Fabrication materials (25 cents per unit; 240 units per shift x 25 cents)	60.00
Shipping containers (24 cents per unit and assume at least partial reuse; 240 units per shift x 25 cents)	60.00
TOTAL	$478.08

Thus for 240 units per shift (at $478.08 per shift) fabrication cost per unit is $1.99; this would utilize 14 lb per unit or 3,360 lb of propellant per shift.

Items that affect the savings are:

1. If the operating personnel can place the fire starters in the shipping containers the cost of shipping will be reduced.

2. The Forest Service is expected to pick up the fire starters at Thiokol and to save the shipping containers so they can be reused.

3. It is also possible that at least part of the labor presently used to package waste propellant in waste containers can be utilized to package the waste propellant in fire starters and thus reduce the cost of producing them.

III. ENERGY CONSERVATION EVALUATIONS OF WASTE PROPELLANT DISPOSAL METHODS

A. OPEN BURNING METHOD

When waste composite propellant is burned, 1,800 Btu (or 0.52 KWH) per pound of energy is liberated and lost. This does not include the energy consumed in making the ingredients or processing the propellant.

A slight amount of energy (0.1 KWH per pound) is also consumed in collection, placing, and igniting the propellant.

The reason that the Btu per pound yield for composite propellant is low. is that 70 percent of the propellant (by weight) is not fuel but oxidizer. Normal fuel uses oxygen from the air when it burns; but even with the energetic materials in propellant, pound for pound Bunker "C" fuel oil and propellant are about equal in energy yield.

B. CONTROLLED BURNING WITH COMBUSTION GAS CLEANUP METHOD

Rotary kilns, fluosolid reactors, and wet oxidation methods of propellant incineration are all designed without any heat recovery system; therefore, there is no net recovery of the energy liberated during burning.

However, in most of the processes some of the heat liberation is utilized to help maintain the combustion temperatures once it has been reached.

Auxiliary fuel (usually oil) is used to get the incineration equipment up to operating temperature. Electrical requirements for fans, rotating mechanisms, air compressors, scrubbers, pumps and control equipment are energy consuming. For these reasons the energy used or lost is estimated to be 0.9 KWH per pound for the controlled burning of waste propellant with gas scrubbing.

C. INGREDIENT RECOVERY METHOD

In the above methods all materials are destroyed. In the proposed ingredient recovery system 0.3 KWH per pound of propellant would be used to operate the recovery plant. The energy conserved by ingredient recovery, based on replacement energy requirements, would amount to 9.8 KWH per pound of propellant.

1. Energy Requirements to Produce Propellant Ingredients

a. Ammonium Perchlorate

Ammonium perchlorate is made by double electrolysis of sodium chloride salt solution.

In the first electrolytic step, sodium chloride is processed to yield sodium chlorate.

In the second electrolytic step, sodium chlorate is processed to yield sodium perchlorate. Sodium perchlorate is then reacted with ammonium chloride to produce ammonium perchlorate.

Recent data from an ammonium perchlorate producer shows 5.3 to 5.7 KWH per pound of AP for the chlorate electrolysis and 1.8 to 1.9 KWH for the perchlorate electrolysis, or an average of 7.1 to 7.6 KWH per pound of AP produced. This contains an allowance for the boiler and refrigeration, but nothing is added for the production of hydrochloric acid and anhydrous ammonia, both of which are used to make the ammonium chloride, nor for the drying of the ammonium perchlorate. Including all of the above, it is estimated that at least 9 KWH of energy are required to make one pound of ammonium perchlorate.

b. Aluminum Powder

Aluminum is produced by the electrolysis of refined alunite (aluminum oxide) dissolved in cryolite (aluminum fluoride at a temperature above 725° C (1,336° F). The energy required to produce one pound of aluminum metal from the alunite is 9.5 KWH. By the time the energy cost of producing alunite from bauxite clays, and the cost of producing an aluminum powder are added in, the energy requirements are near 14 KWH per pound of aluminum powder produced.

c. Polymer and Epoxy Curing Agent (ECA)

The heat of formation of polymer is 10,800 calories per gram. This would be 19,440 Btu per pound or 5.7 KWH per pound, which is a conservative figure. Allowing for processing equipment operation and efficiencies, a value of 9 KWH per pound would be more realistic. This number will be used for both polymer and ECA because of the similarity of their preparation.

2. Energy Requirements for Proposed Ingredient Recovery Process

The following assumptions are made:

1. The plant, when operating at full capacity, will process 21,000 pounds of propellant per day.
2. The propellant shredder will operate at 75% load for 10.5 hours per day.
3. The process water stream will average 5 gallons per minute and be heated to 190°F (88°C).
4. Crystallization will take place at 95°F (35°C).
5. ˙or heating pipes, tank jackets, and space ting the heat requirement will be tripled.
6. The transesterification method of residue treatment will be used in the calculations.

	Energy Requirements Per Day
Electrical Power	619.8 KWH
Process and Space Heating Steam (22,181,000 Btu per day)	5,880.2 KWH Equivalent
TOTAL	6,500.0 KWH

When processing 21,000 pounds of propellant per day, the energy requirements per pound would be 0.31 KWH.

The energy value of the ingredients of one pound of propellant are:

		Energy Requirements (KWH)	
	Quantity Per Propellant Pound	Per Ingredient Pound	Per Propellant Pound
Ammonium Perchlorate	0.70	9	6.30
Aluminum	0.16	14	2.24
Polymer and ECA	0.14	9	1.26
Total Energy Required to Replace 1 Pound of Propellant			9.80

The net energy saving per pound of propellant processed would be (9.8 minus 0.31) 9.49 KWH. The Space Shuttle program is expected to produce 7,962,600 pounds of propellant and 2,800,000 pounds of waste ammonium perchlorate in the 14 year production period. The energy savings that could be expected would amount to 75.6 million KWH of power for the processed propellant and 24.3 million KWH for the waste ammonium perchlorate processed. This savings would amount to approximately 100 million KWH of energy in the 14 year period.

Figure 4 graphically illustrates the energy relationship between disposal methods and points out the energy advantage of ingredient recovery.

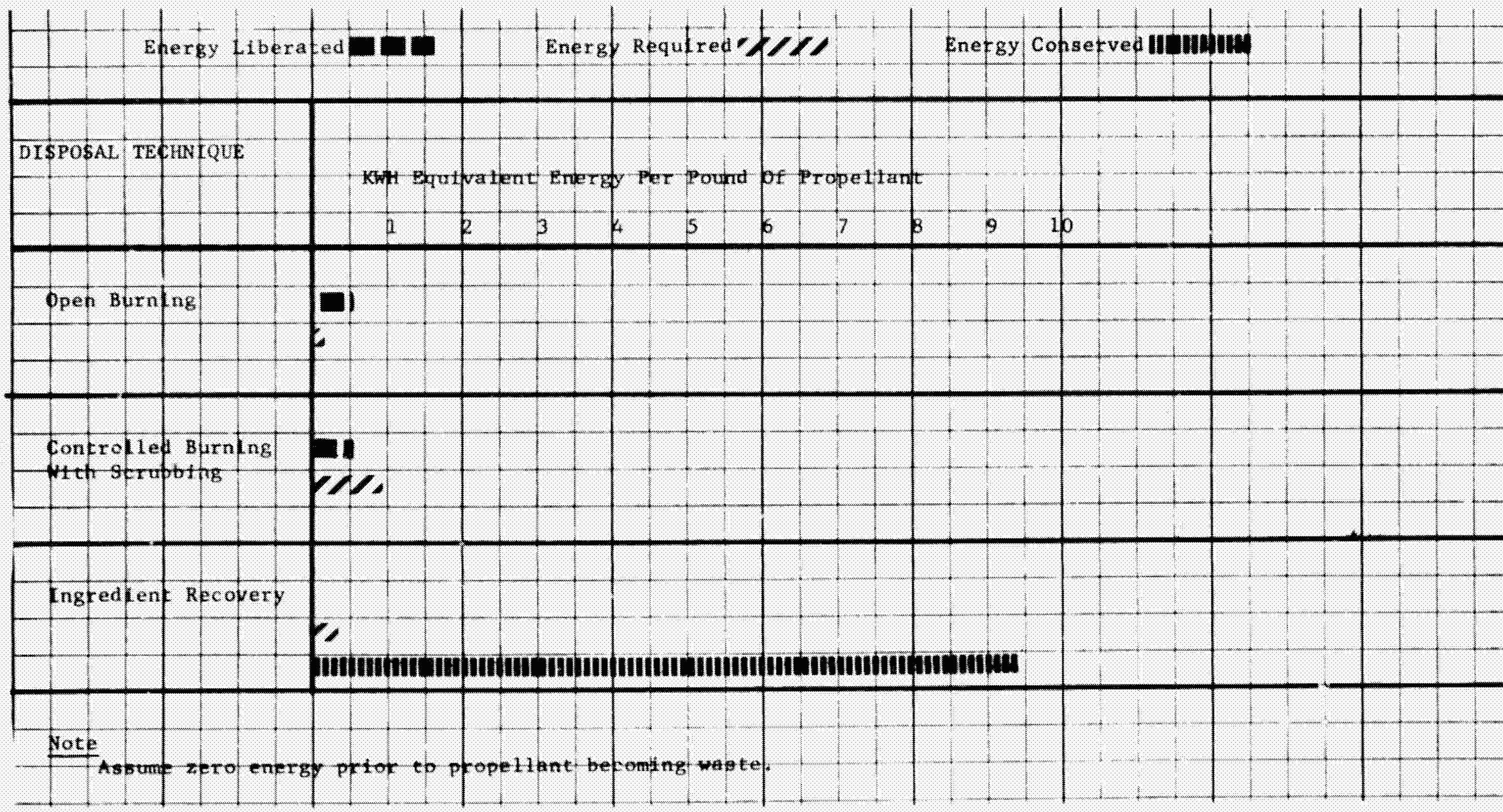


Figure 4. Energy Relationship for Various Disposal Methods

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The economics of waste propellant disposal indicate that the shift from open burning to one of the controlled burning methods is costly. New equipment costs as well as higher operating costs will be encountered.

The recovery of ingredients from waste propellant (when there is a large supply of composite propellant) can be a self-supporting operation. It is predicted that for the Space Shuttle program over $1.5 millions can be saved by recovery of ammonium perchlorate and aluminum.

The energy study balance is also in favor of ingredient recovery. The savings in energy on the same Space Shuttle program would amount to 100 million KWH of energy, while open or controlled burning represent a total loss of energy.

B. RECOMMENDATIONS

It is recommended that the detailed design of a recovery plant be initiated.

It is also recommended that a plant funding effort be initiated. The goal should be to have an ingredient recovery plant onstream prior to the start of the Space Shuttle production effort in 1977.