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LEAD INDUSTRIES ASSOCIATION, INC.

292 MADISON AVENUE
NEW YORK, N. Y. 10017
TELEPHONE – AREA CODE 212
[illegible]

ISC

February 23, 1966

SUBJECT: EVALUATION OF USE vs.
NON-USE OF TEL IN GASOLINE

To Members of: Board of Directors and
Industry Development Committee of the
Lead Industries Association, Inc.

Attached please find a copy of the report entitled "Evaluation of Use versus Non-Use of TEL in Gasoline" presented by the Ethyl Corporation at the Public Health Service Symposium on environmental Lead Contamination held in Washington, D.C. in December, 1965.

Because of the limited number of copies made available to us, your alternate has not received a copy of the report.

Sincerely yours,

David M. Borcina

DMB:so

Secretary-Treasurer

Look Ahead with Lead

EVALUATION OF USE vs. NON-USE OF TEL IN GASOLINE

ETHYL CORPORATION
Ferndale, Michigan

December 1965

LIA16935

EVALUATION OF USE vs. NON-USE OF TEL IN GASOLINE

Lead antiknocks are an essential ingredient in gasoline. Their use conserves natural resources. They are used for economic reasons and thus I wish to direct your attention primarily to an appraisal of economic aspects of the "Evaluation of Use vs. Non-Use of TEL in Gasoline."

First, a word about our refinery technology operations might be in order. Our Refinery Technology activity is an engineering organization whose principal function is to help petroleum refiners make the most efficient use of antiknock compounds. Over the years, this group has worked closely in literally hundreds of studies with essentially every gasoline manufacturer in this country and many more throughout the Free World on one phase or another of problems related to gasoline manufacture, blending, and use. Our work primarily involves consulting services on the optimum use of antiknocks. This area, in turn, involves:

1. The most efficient operation of processing equipment to produce gasoline components.

2. The most efficient blending of gasoline components to finished gasoline.

3. The tailoring of the antiknock quality of gasolines to the octane-number requirement of automobiles.

Because optimum utilization of antiknock compounds has a direct bearing on all of these functions, this study draws on our extensive, thorough, and authoritative background in discussing the economic aspects of the use of lead antiknock compounds in gasoline.

At this time, I would like to highlight the results of two studies. The first is an appraisal of the effect of elimination of lead from gasoline on the U.S. Petroleum Refining Industry as a whole. The second will be a description of the situation faced by a moderately sized refiner in order to illustrate the nature of problems individual refiners would encounter.

Petroleum refining economics is a complicated subject. For this reason, sound studies of economics must be complex and must use the latest tools of economic analysis. Any simple approach will tend to overlook important considerations. Recognizing this complexity, in both studies we have used the modern management science technique known as linear programming to simulate refinery operations, with solutions obtained through the application of large electronic computers. Today, this approach is recognized as the standard and accepted method for such investigations. Because we have not taken a simple approach, my subject matter is also necessarily fairly complex.

For the industry study, we employed a model that simulates the operation of the entire U.S. refining industry. This model is used by Ethyl to forecast future demand for antiknock compounds. It effectively reproduces industry activity in historical periods on which statistical data permit a check. Furthermore, we have had extremely good success at prediction of near-future demand with this model. In the lead use vs. non-use study, simulated situations evaluate the effects of producing gasoline without lead antiknocks in contrast to a base case that reflects present-day operations with lead. We compare least-cost situations with lead to least-cost situations without lead so that each way of operating is fairly represented.

This Table (1) presents for the U.S. refining industry raw material intake and product distribution for the base case using lead and a case simulating how the industry would be forced to operate if lead antiknocks were unavailable. Raw material prices and product values assumed for this study also are shown in this table. For the leaded base case, the volumes of raw material intake and the volume of products heavier than butane are consistent with published statistics for 1963. Statistical data for 1963 are used in this study since this is the latest annual period for which complete information was available at the time work was started.

The "no lead" case makes the same volume as the leaded case of all products heavier than butane. This is the only reasonable assumption that can be made since the industry would have to satisfy the demand for all products whether lead antiknocks were available or not.

It has been assumed for simplicity that aviation gasoline can be made in the "no lead" situation. Actually, this assumption is not really valid since high-quality aviation gasoline cannot be made if lead antiknocks are unavailable.

Excess hydrogen, fuel gas, and propane are valued as fuel in both the lead case and the simulated "no lead" case. Butane is valued at 6¢ per gallon in the leaded base, which is consistent with current values. It is valued at fuel price in the case without lead because fuel gases are produced in excess of base volumes and because light hydrocarbons become impractical components for gasoline blending with the type of processing required to manufacture unleaded gasolines.

In the "no lead" case, crude oil and natural gas liquids intake are allowed to vary to permit attempted production of the same quality and quantity of petroleum products as in the leaded base case. As a result, crude oil consumption increases more than one million barrels per day and the consumption of natural gas liquids decreases to zero, with an overall increase in total petroleum raw materials of about 1/2 million barrels per day. Overall, raw material intake increases by more than 5%. However, the consumption of crude oil increases by more than 10%. We are convinced that the manufacture of gasolines without lead antiknocks would be very destructive of our petroleum natural resources.

The consumption of natural gas liquids decreases for the same reason that the value of butane must be degraded. The type of processing required to manufacture unleaded gasolines makes the highly volatile natural gas liquids impractical raw materials for petroleum-refining operations. Consequently, the natural gas industry would have to find alternate uses for these materials or they would become low value by-products of natural gas production.

This Table (2) shows processing investment and operating costs for the various types of processing considered available in this study. Investment costs which are expressed as dollars per barrel of capacity, include a charge of 20% of processing unit cost for the cost of off-site facilities and can be thought of as average costs to the whole industry or as specific costs to refineries with crude running capacity of roughly 75,000 B/D. Unit, fixed, and incremental costs are all expressed on a calendar-day basis. Fixed costs are equivalent to 36% per year of capital investment. Included are charges for increased maintenance, insurance, property taxes, depreciation, interest on borrowed capital, income taxes, and return on investment. No charge for increased working capital has been made in this study to cover such factors as the increased inventory of crude oil, catalyst, and hardware that would be required. No allowance has been made for the increased operating labor, supervision, and technical support of operations that would be needed with the increased complexity of operations.

This Table (3) shows, for the U.S. refining industry, the throughput of material for various petroleum-refining processes. Again, the data for the leaded base case are consistent with the availability of various types of processing facilities in the U.S. refining industry in 1963. For unleaded gasoline, the figures shown represent the capacity required to produce the slate of products demanded of the industry. The next column of figures reflects the new processing required by the industry to make gasolines without lead. No excess capacity is assumed in the no-lead case just as no excess capacity has been assumed for the leaded base case.

The investment in new processing facilities required to permit the U.S. petroleum refining industry to produce gasolines without lead anti-knocks would be about $3,000,000,000. This is roughly 1/3 of the industry's current total investment in petroleum refinery process facilities. Further, it is six or seven times the current high annual level of capital expenditures in new petroleum refining facilities; and current expenditures are straining the capabilities of construction companies. Current expenditures are being used for expansion of manufacturing operations to provide for growth in demand, to improve product quality, and to increase the efficiency and flexibility of current operations. The multibillion dollar investment required to make gasolines without lead would not provide for needed growth, quality, flexibility, and efficiency. In fact, a loss in flexibility, efficiency, and gasoline quality from current levels would be experienced without antiknocks.

This Table (4) shows, for the U.S. refining industry, the properties of gasolines produced in the lead case and in the case with no lead. In the leaded base case, Research and Motor octane numbers for premium and regular gasolines are U.S. average values for 1965. Volatility properties of lead case premium and regular gasolines are average U.S. values for all areas and all seasons of the year and are derived from Bureau of Mines survey data. These properties are Reid vapor pressure and percent of gasoline evaporated at the stated temperatures in degrees Fahrenheit. Hydrocarbon-type analyses for the leaded base-case gasolines are calculated from the composition of gasolines obtained in the simulation of the U.S. refining industry and are representative of today's fuels.

Moving on to the specification column, present-day Research and Motor octane numbers have been used as minimum standards for fuels produced without lead antiknocks. The volatility specifications for unleaded gasolines have been set so as to provide reasonably satisfactory performance, although somewhat less satisfactory than average leaded gasolines. It is practically impossible to produce gasolines without lead that would have the same volatility characteristics as present-day fuels and at the same time approach current standards of octane quality. Thus, we have assumed U.S. average volatilities could shift somewhat from present averages but that the limits of the current range of gasoline volatilities would be the limits of acceptability and that the U.S. average volatility would have to fall within this range and could not be on either extreme.

Hydrocarbon-type specifications are not imposed on either the lead case or the "no lead" case.

Now let's consider the last column, which shows the gasoline properties for the no-lead case. Experimental and commercial data show that gasolines produced without lead antiknocks become more sensitive; that is, the differences between Research octane number and Motor octane number increases. Thus, Research octane number must be raised above current levels to maintain current Motor octane number. For premium gasoline made without lead, Research octane number goes from 100.0 to 101.3 to maintain the Motor octane number at 91.2. For regular gasoline, the Research octane number increases from 93.9 to 96.9. Experience and experimental data show that, despite the higher Research octane number, these unleaded fuels are more prone to knock in cars on the road than today's leaded gasolines. A recent study involving ten cars and fuels similar to those shown in this table verifies this conclusion. Thus, gasolines made without lead antiknocks will satisfy fewer of the cars on the road than leaded gasolines, --- even if laboratory octane quality is maintained.

Although we have attempted to maintain reasonable control on the volatility quality of gasolines produced without lead, the premium gasoline tends to become heavier. Without some volatility specifications, it would become much more so. On the other hand, the regular grade gasoline becomes more volatile for the no-lead case. Again, this tendency would be more pronounced without reasonable volatility specifications. Directionally, these problems become very severe if a significant part of the required capital investment is not devoted to control of gasoline volatility. But, if we ignored volatility specifications, the resulting premium fuel would be unsatisfactory in warm-up characteristics and would produce higher hydrocarbon emissions. On the other hand, the regular grade gasoline would be unsatisfactory in terms of cold weather carburetor icing and warm weather vapor-lock tolerance, and the evaporative losses would become severe.

It is desirable to have similar volatility in both grades of gasoline - both from civilian and military points of view. Today's premium and regular gasolines have similar volatilities but this practice would become impractical if lead were not available. Again, the hydrocarbon type analyses for the no-lead situation are calculated from the compositions of the gasolines obtained in the simulation study.

This Table (5) summarizes the main conclusions from this part of the study and shows the increased cost of manufacturing gasoline if lead antiknocks were not available. The cost of making gasolines approaching the quality of today's gasolines without using lead antiknocks is estimated to be 2.6¢/gallon for the U.S. refining industry as a whole. This is a 30% increase in the manufactured cost of gasoline (including raw material cost) based on an assumed present-day cost of 8.5¢/gallon for an efficient large refinery. Principal components of the increased cost of gasoline are the increased consumption of petroleum raw materials (185,000,000 barrels/year) and the enormous capital investment (3 billion dollars) in new process facilities that would be required. The type of gasolines which would have to be produced without lead would be less satisfactory than today's fuels and would require serious consideration with regard to certain problem areas.

1. Premium gasolines would become heavier, and thus would have poorer warm-up properties and produce higher hydrocarbon emissions.

2. Regular gasolines would become lighter, and therefore would be prone to carburetor icing, would have less resistance to vapor lock and would produce higher evaporative losses.

This Table (6) highlights three other areas that should be considered. Reduced flexibility of refining operations is a serious problem that would face the industry if antiknock compounds were unavailable for use in gasoline blending. This loss of flexibility manifests itself in two ways:

1. It would reduce the industry's current capacity for providing emergency supplies of gasolines, jet fuels, and specialities on short notice. Refiners would no longer be able to incorporate large volumes of marginal gasoline stocks or release potential high-octane gasoline feedstocks or high-octane components for other uses.

2. It would complicate gasoline blending. Increased time and effort would be required to blend gasoline from components. Inventories of components would have to be larger. This loss in efficiency has been estimated to require an increase of at least one-half number for all octane targets to assure satisfying specifications.

It has been suggested by a few individuals that, rather than restore present octane quality with processing, cars should be modified to operate on the quality of gasoline that could be produced by simply leaving lead antiknocks out of gasoline. Assuming that present-day cars could be made to perform on fuels of that quality as well as they perform on present fuels (and this assumption is not valid), fuel economy would be adversely affected. An estimated 10% increase in gasoline consumption would result. This increased gasoline consumption would cost the motorist an additional 2 billion dollars per year based on a gasoline price of 30¢/gallon as well as depleting crude oil resources and increasing total hydrocarbon emissions proportionately.

Still another factor should be considered. If forced to operate without antiknocks, the refining industry would be dependent to an even greater degree on the availability of platinum catalyst for catalytic reforming as a means of producing needed octane quality ---both in normal times and in times of emergency. Since platinum is not a native raw material, the United States is subject to the availability of this metal in the world market. The principal world source of platinum is the Soviet Union, with South Africa a secondary source. Very small amounts are produced in the Western Hemisphere.

We estimate that the present capacity for catalytic reforming

1. Higher average octane quality on both premium and regular gasoline.

2. Slightly higher percentage of premium gasoline on total gasoline.

3. Higher percentage of gasoline on crude.

4. Smaller size processing units, resulting in higher capital costs in $/barrel of capacity, less flexible operations, and limited sizes of economically justified unit operations.

The current investment in process facilities for this refinery is about 20 million dollars.

In this Figure (2) the additional processing units required to manufacture gasolines without lead antiknocks are shown. The required investment in new processing facilities totals 13-1/2 million dollars or about 2/3 of the total current investment.

At the present time, the management at a refinery of this size could well be seriously considering the relative advantages and disadvantages of adding a hydrocracker to the present processing scheme. In such consideration, a major concern would be whether the "1 million dollar" investment can be justified in terms of improved product distribution or quality or even the banker's willingness to finance such an investment. For this refiner, contemplating a $13-1/2 million investment in new facilities seems impossible with no improvement in produce quality, or product slate, or operating efficiency.

The problem areas noted for the U.S. refining industry apply for this illustrative refinery as well, but become more severe. Premium gasoline would become heavier, and regular gasoline would become more volatile. These properties would be harder for the small refiner to hold in line. Petroleum raw material intake would increase about 10% and the manufactured cost of gasoline would increase almost 4¢/gallon, or about 45%.

Assuming that the cost of manufacturing unleaded gasolines could be passed from the refiner to the motorist, injustices would inevitably be created. Refiners with costs lower than the average would benefit whereas refiners with costs above the average (such as the one illustrated) would suffer. Directionally, the small refiner, whose costs would almost always exceed the average, would be hurt the most. At least 100 small refineries (roughly 1/3 of the total number of refineries in the United States) would probably have to be closed. We have been told by small independent refiners that they would be unable to compete in the gasoline manufacturing business if antiknocks were unavailable to them as a means of producing competitive antiknock quality. These refiners would be forced out of the petroleum refining business.

Table 1

U.S. REFINING INDUSTRY INTAKE AND PRODUCTION

	Raw Material Price $/B	Leaded Base M B/D	No Lead M B/D	Increase for No Lead Case M B/D
Intake				
Crude Oil	3.05	8,717	9,800	1,083
Natural Gas Liquids	2.31	579	--	-579
Unfinished Oils	--	87	87	--
Total Petroleum Raw Material		9,383	9,887	504
Production				
Excess H_2, M SCF	10 ¢/MSCF	763	497	-266
Fuel Gas, FOE - 30.5 ¢/$\overline{M}$ Btu	1.92	339	581	242
Propane - 30.5 ¢/$\overline{M}$ Btu	1.17	268	585	317
Butane - 6 ¢/gal.	2.52	139	442*	303
Premium Gasoline @ 12.3 ¢/gal.	5.15	1,409	1,409	--
Regular Gasoline @ 10.5 ¢/gal.	4.41	2,835	2,835	--
Aviation Gasoline @ 13.0 ¢/gal.	5.46	146	146	--
Naphtha Specialties	6.30	62	62	--
Petrochemicals	6.68	113	113	--
Military Jet Fuel	3.89	226	226	--
Kerosene & Comm. Jet Fuel	3.57	495	495	--
Diesel Fuel	3.36	628	628	--
Heating Oil	3.30	1,466	1,466	--
Residuals & Road Oils	2.05	777	777	--
Lubricants	10.29	173	173	--
Asphalt & Wax	2.55	321	321	--
Coke, Tons	12.00	89	89	--
Miscellaneous	8.40	99	99	--

* Valued @ 30.5 ¢/$\overline{M}$ Btu

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Table 2

U.S. REFINING INDUSTRY PROCESSING INVESTMENT & OPERATING COST

	Investment Costs* $/B of Capacity	Operating Cost, $/B Fixed**	Operating Cost, $/B Incremental
Processing Equipment			
Cat Cracking	400	0.3944	0.10-0.12
Hydrocracking	720	0.7099	0.36-0.38
Alkylation	1,017	1.0027	0.55-0.99
Isomerization, C_5 - C_6	440	0.4338	0.30
Cat Reforming	400	0.3943	0.19-0.48
Hydrotreater	200	0.1972	0.05
Extraction	467	0.4605	0.20
Fractionation	26-67	0.0256-0.0660	0.02
Hydrodealkylation	1,071	1.0560	0.69
Crude Unit	100	0.0986	0.10
Hexane Isomerization	512	0.5048	0.30
BTX Facilities	--	--	0.25
Polymer Plant	--	--	0.45
Thermal Processing	--	--	--
Coker	--	--	0.11
Cracker	--	--	0.10-0.20
Visbreaker	--	--	0.05
Alkylation Revamp	165	--	--
Cat Reforming Revamp	50	--	--

* Includes 20% of battery-limit installation for off-site.

** 36% of capital investment per year. Includes 4% maintenance, 2% insurance and taxes, 30% depreciation, interest, and return on investment.

Table 3

U. S. REFINING INDUSTRY PROCESSING THROUGHPUTS

	Leaded Base M B/CD	No Lead M B/CD	New Processing Required M B/CD	Investment $/B	Investment MM $
Crude Fractionation	8,717	9,800	1,083	100	108
Catalytic Cracking, Fresh Feed	3,545	3,442	--	400	--
Hydrocracking	38	849	811	720	584
Thermal Processing	1,127	764	--	--	--
Catalytic Reforming	1,688	3,505	1,817	400	727
Extraction	--	1,075	1,075	467	502
Hydrodealkylation	--	113	113	1,072	121
Isomerization, C_5 - C_6	8	958	950	440	418
Isomerization, C_6	--	--	--	512	--
Alkylation	416	447	31	1,017	31
Polymerization	99	59	--	--	--
Hydrotreating	238	663	425	200	85
Fractionation of:					
Cat Cracked Gasoline (Lt/Hvy)	620	1,481	861	26	22
Cat Cracked Gasoline (C_5/C_6/Hvy)	--	--	--	--	--
Thermal Gasoline (Lt/Hvy)	336	148	--	--	--
Reformate (C_5 - C_6/C_7+)	--	2,514	2,514	26	65
Isomerate (C_5/C_6)	--	395	395	67	26
Lt. Hydrocracked	--	229	229	67	15
Lt. Thermal	--	86	--	--	--
Alkylation Revamp	--	416	--	165	69
Catalytic Reformer Revamp	--	1,688	--	50	84
					2,857

Table 4

U.S. REFINING INDUSTRY GASOLINE PROPERTIES

	Leaded Base	Specifications	No Lead
Premium			
Research Octane Number	100.0	100.0 min.	101.3
Motor Octane Number	91.2	91.2 min.	91.2
TEL, ml/gallon	2.54	0.0 max.	0.0
Reid Vapor Pressure, psi	10.2	10.2 max.	10.2
% Evaporated @			
158°F	28	25 min.	27
180°F	36	50 max.	34
240°F	62	57 min.	57
356°F	97	90 min.	99
Hydrocarbon Type, Vol %			
Aromatics	22	--	47
Olefins	16	--	--
Saturates	62	--	53
Regular			
Research Octane Number	93.9	93.9 min.	96.9
Motor Octane Number	85.5	85.5 min.	85.5
TEL, ml/gallon	2.05	0.0 max.	0.0
Reid Vapor Pressure, psi	10.2	10.2 max.	8.2
% Evaporated @			
158°F	32	20 min.	32
180°F	43	47 max.	47
240°F	62	50 min.	67
365°F	95	90 min.	100
Hydrocarbon Type, Vol %			
Aromatics	17	--	35
Olefins	20	--	21
Saturates	63	--	44

Table 5

U.S. REFINING INDUSTRY SUMMARY

COST OF MAKING GASOLINE WITHOUT LEAD ANTIKNOCKS

Increased Cost of Manufacturing Gasoline 2.6¢/gal. of gasoline

Percent Increase in Manufactured Cost 30%

Increased Petroleum Raw Material Consumption	barrels/year	$
Crude Oil	396,000,000	12
Natural Gas Liquids	-211,000,000	
Net Increase	185,000,000	5

Investment in New Processing Facilities $3,000,000,000

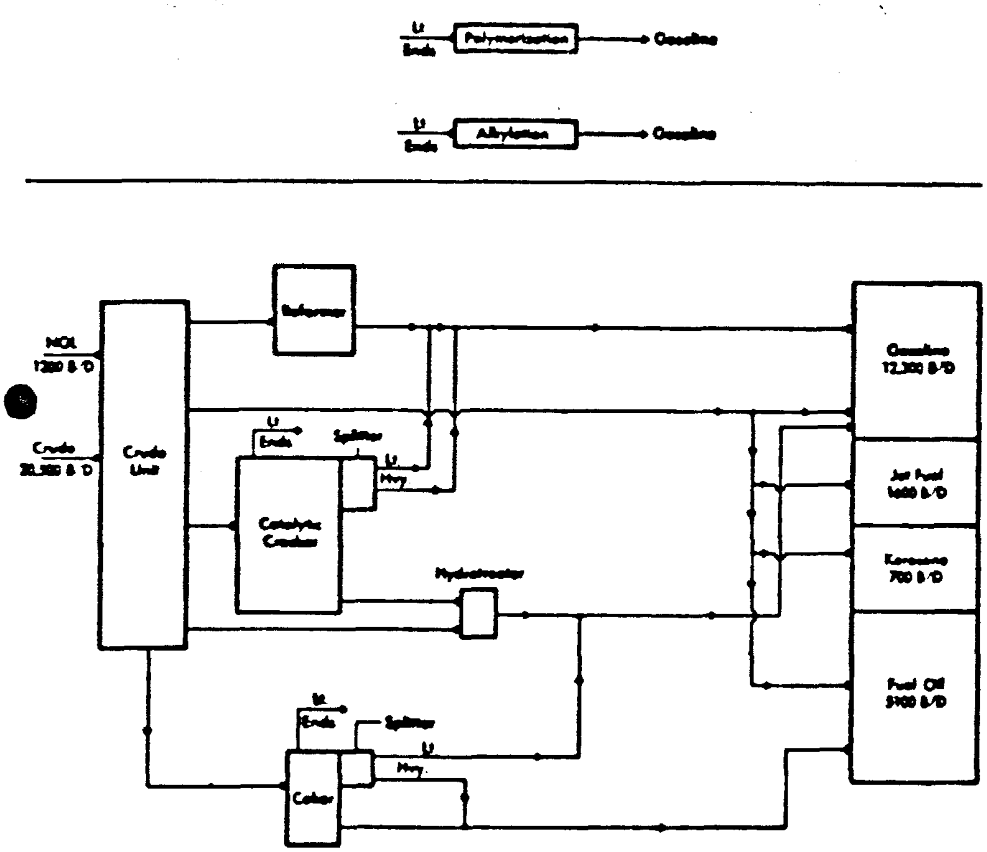
PROBLEM AREAS

Premium Gasoline heavier (poorer warm-up and higher hydrocarbon emissions)

Regular Gasoline lighter (more prone to vapor lock and higher evaporative losses)

Figure 1

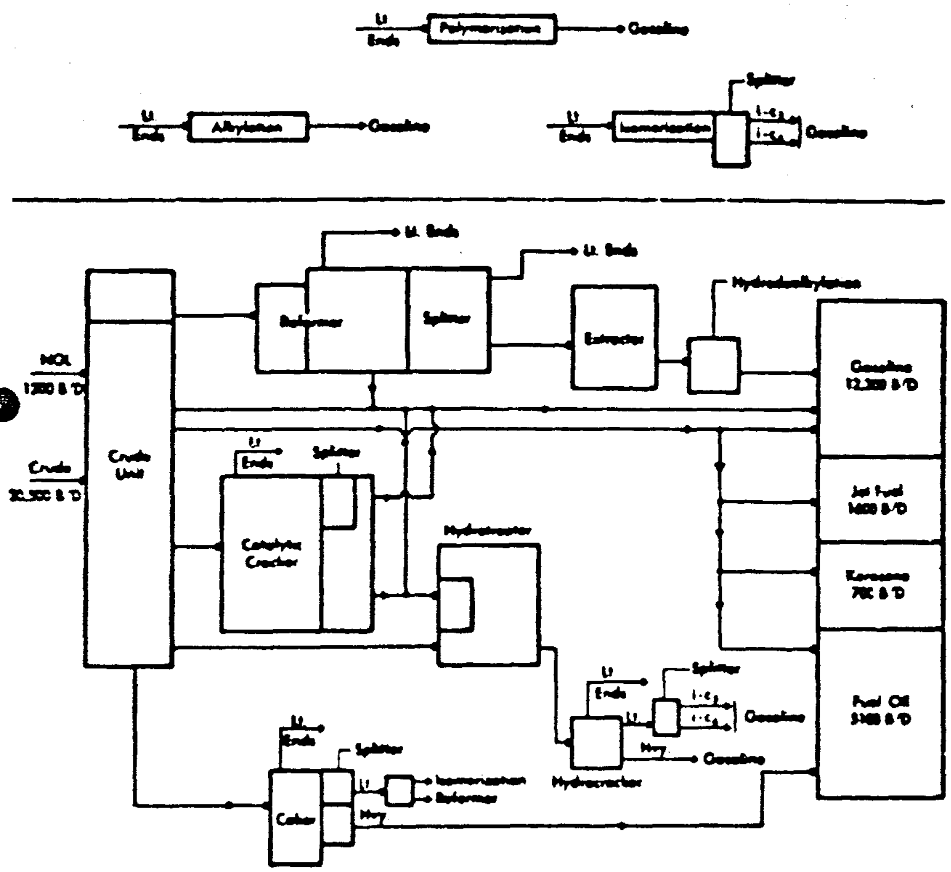
REFINERY USING LEAD



Represents $30,000,000 Investment

Figure 2

REFINERY USING NO LEAD



Represents Additional $13,300,000 Investment