PRELIMINARY ECONOMIC ESTIMATES FOR PRODUCTION OF POTASSIUM METAPHOSPHATE AT GREEN RIVER, WYOMING

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Summary:

Four flow sheets have been analyzed for the manufacture of potassium metaphosphate at Green River, Wyoming, and all show the possibility of profitable operation. The principal results of this analysis are summarized in Table #1 and the flow sheets are illustrated in accompanying flow sheets #1, 2, 3, and 3A. The location of the resources tributary to Green River is shown on the accompanying map.

TABLE #1.

Summary of Economic Estimates
Covering Manufacture of 100,000 tons annually
Potassium Metaphosphate and By-Products at
Green River, Wyoming.

Flow Sheet No.	Investment	Net Sales	Net Profit before Federal Taxes.	Net Return on Investment after All Charges
1	$12,668,700.00	$6,334,350.00	$1,862,200.00	14.7%
2	14,316,000.00	7,158,000.00	2,078,940.00	14.5%
3	14,157,600.00	7,078,800.00	1,718,200.00	12.2%
3A	14,157,600.00	7,078,800.00	1,830,200.00	12.9%

In all of the flow sheets a coke fired blast furnace is utilized for the production of a potash bearing phosphoric acid, and the additional potash required for making potassium metaphosphate is provided by base exchange between a sodium salt and wyomingite.

In all of the flow sheets except #1, ninety tons daily KCl containing 62% K_2O is produced in addition to 305 tons 92% potassium metaphosphate, which latter production is common to all of the flow sheets.

In analyzing the markets for potassium metaphosphate, it has been assumed that the following percentage of total sales will be captured in the states listed:

Both the Sunnyside coal from Utah and the Trinidad coal from Colorado are coking coals, and preliminary tests of the Parr process carried out at the University of Illinois, Urbana, Illinois, showed that a good metallurgical coke could be made from a mixture of 60% Rock Springs non-coking coal and 40% Sunnyside coal.

(2) Pilot plant work should be done on the proposed process described by K. G. Clark in correspondence with the writer for the direct combination of potassium chloride and phosphoric acid in equi-molal quantities for the production of potassium metaphosphate.

(3) The resources of the Green River soda brine should be explored.

(4) As a final check, a complete pilot plant operation should be set up in which each step of the process would be carried out and in which the coke, which it would be proposed to use, would be employed in the small blast furnace.

This paper covers a preliminary economic survey to determine the present day economic possibilities and competitive position of the proposed industry for the manufacture of potassium metaphosphate and by-products at Green River, Wyoming. The paper is based upon data of laboratory and pilot plant research by the writer in 1926-1927. The results of this work are covered in an unabridged report by the writer and his associates in four volumes containing thirty-five subdivisions. References to this report in this paper will be given in the text by the letter "R" followed by the number of the subdivision. A copy of this unabridged report is in the possession of the writer and may be examined. In addition the writer has published abridged accounts of his work as follows:

"Volatilization of Phosphorous from Phosphate Rock," Robert D. Pike, Industrial and Engineering Chemistry, v.22, 344 (1930). Parts 2 and 3. Reference in text, P-1.

"Proposed Manufacture of Monopotassium Phosphate at Green River, Wyoming," Robert D. Pike, Industrial and Engineering Chemistry, v.25, 256 (1933) Parts I and 2. Reference in text, P-2.

"Proposed Manufacture of Monopotassium Phosphate at Green River, Wyoming," Robert D. Pike, Industrial and Engeineering Chemistry, v.25, 374 (1933) Parts 3 and 4. Reference in text, P-3.

Reference has also been made to the following:

Blast Furnace Processes for the Production of Phosphatic and Potassic Fertilizer Materials, P. H. Royster, K. D. Clark, T. P. Hignett, L. E. Bowe, H. I. Landon, J. C. Southard, J. W. Turrentine, Tech. Bull. 543, U. S. Department of Agriculture (1937).

This paper covers four alternative flow sheets for the manufacture of potassium phosphates and by-products at Green River, Wyoming, viz: 1, 2, 3, and 3A. Flow sheets 1 to 3 inclusive may be employed to manufacture either monopotassium phosphate or potassium metaphosphate; flow sheet 3A produces only potassium metaphosphate and employs a process proposed by K. G. Clark for the direct combination of KCl and phosphoric acid in equi-molal quantity. Clark reports that work on this process has not as yet gone beyond the laboratory stage, but that it looks promising.

In the writer's earlier work (P-1) he used oxygen for enriching the blast in order to obtain a sufficient thermal head to volatilize phosphorous with good economy of fuel. Since then Royster developed his stove which can deliver an air blast at 2000° F. and the writer has assumed the use of the Royster stove in these estimates.

The writer originally proposed the manufacture of a crude monopotassium phosphate containing 80% total available and water soluble plant food (P-3). This salt has good water solubility and is non-hydroscopic. Potassium metaphosphate is easily prepared by the moderate heating of monopotassium phosphate, water being driven off thus

$$KH_2PO_4 \longrightarrow KPO_3 + H_2O$$

Potassium metaphosphate is water insoluble but otherwise contains 100% plant food thus

$$2KPO_3 = K_2O + P_2O_5$$

By heating the crude monopotassium phosphate, a crude metaphosphate would be formed containing about 92% $K_2O + P_2O_5$, and this is the salt which is referred to in the estimate although it is likely that flow sheets 3 and 3A would produce a somewhat higher grade salt.

Because potassium metaphosphate is insoluble in water, its value as a plant food had to be demonstrated. This, we are informed, has been successfully done by the Department of Agriculture. This is of great importance because of the extraordinarily high concentration of plant food in this salt and because the ratio of K_2O to P_2O_5 which occurs in it is very close to that used in all of the United States east of the Rocky Mountains. This salt can therefore be employed directly in a very large proportion of the mixed fertilizers used throughout the United States except in California.

The manufacture of potassium metaphosphate at Green River would have great significance to the agricultural economy of the Middle west and at the same time its great concentration would enable it to be shipped to all sections of the United States in competition with the present supplies of phosphoric acid and potash.

The Flow Sheets, General Discussion:

All of the flow sheets which are illustrated in the accompanying diagrams include a blast furnace for the production of a potash bearing phosphoric acid (P-1), and in all of them this acid is neutralized with potash salt made by base exchange with wyomingite (P-2-3, R-10). The coke for the blast furnace is made in by-product coke ovens from a mixture of 60% Rock Springs coal and 40% Sunnyside coking coal (R-2). This mixture in accordance

with the Parr process is given a heat treatment prior to coking. Tests made at the Parr laboratory, University of Illinois, Urbana, Illinois, showed that this procedure produced a strong metallurgical coke.

But this should be carried out on a larger scale and the Trinidad coking coal should be included within the scope of investigation.

The variations in the flow sheet arise from alternative use of Green River soda water or common salt from Salt Lake in the base exchange process; and from the alternative use of the writer's process (P-3, R-16), or the Department of Agriculture's proposed process for combining phosphoric acid with potassium chloride.

A considerable amount of potassium chloride may be advantageously produced in the base exchange process as a semi-by-product because of the availability of steam heat at no additional expense for fuel which is recovered as a by-product from the blast furnace operation. Also in some of the flow sheets there is a considerable amount of surplus gas available at no cost which could be utilized for the production of very cheap electric power.

In all of the flow sheets important by-products occur, viz: ammonium sulphate, coal tar and benzol fractions, and ferro-phosphorous. These by-products may be depended upon for an important source of income. In addition to them, flow sheets # 1 and 2 may produce soda ash in sufficient quantity to supply the needs of the Inter-Mountain region amounting to about ten tons daily.

The Markets and Probable Value of
Main and By-Products at the Plant:

In all of the flow sheets the production is placed at 175 tons P_2O_5 and 105 tons K_2O daily in the form of the main product, 92% potassium metaphosphate; 10 tons ammonium sulphate; 7 long tons of 24% ferro-phosphorous; 3000 gallons benzol; 11,500 gallons coal tar. Flow sheets #1 and 2 produce ten tons daily of soda ash. Flow sheets #2, 3, and 3A produce 90 tons daily KCl containing 62% K_2O.

The principal sources of published authorities on the markets for fertilizer which have been referred to in the preparation of this paper are:

"A Survey of Plant Food Consumption in the United States for the year ending June 30, 1934," A. L. Mehring, H. R. Smalley, reprinted from Proc. 11th Annual Convention of the National Fertilizer Association, 1935.

Fertilizer Consumption of the United States, Hubert Willett, National Fertilizer Association, 1937.

Oil, Paint and Drug Reporter is depended upon for current quotations, supplemented by private information from various sources.

Quotations on freight rates prepared by Union Pacific officials in 1927 have been used to provide normal present day rates. Where these rates do not supply the required information the present published rates on potassium chloride from Loving, New Mexico, are used.

It is possible that rail rates may be raised in the future, but the principal markets for the product are in areas away from the seaboard so that, as rates are raised, so also will be the quotations upon phosphoric acid and potash in the most available markets. On this account any probable increase in freight rates would not be expected to materially change the conclusions which have been reached.

The freight rates referred to above which were quoted by Union Pacific officials in 1927 follow:

From Green River on Potassium Phosphate to	Per Net Ton
Chicago	$ 7.80
St. Louis	6.80
Kentucky points	9.50
Michigan points	9.50
Indiana points	9.50
western New York and Pennsylvania	10.00
Ohio	10.00
Texas	8.90
Arkansas, Louisiana, and Oklahoma points	10.40
San Francisco, Los Angeles, Portland, Seattle	6.80
Portland for export	4.00

Incoming Rates to Green River

Wyomingite from Superior, Wyoming	.50
Phosphate rock, Georgetown, Idaho, to Green River	1.75
Salt from Salt Lake producing points (This rate probably can be bettered.)	4.00
Lime rock, Rawlins, Wyoming, to Green River	1.40
Coal, Sunnyside, Utah, to Green River (Utah Fuel advise rate to Pocatello, Idaho, about the same distance, is now $2.90 and we use this lower figure in the estimates.)	3.75
Sulphuric acid in tank cars, Garfield, Utah, to Green River (We are advised that the present rate from Garfield to Parco is $7.70 per ton, and based upon this we have used a figure of $5.00 in our estimates.)	4.00

Current Freight Rates
Muriate of Potash c/l Rail
Fertilizer or Other than Fertilizer
From Loving, New Mexico

Rates per ton.

To	Minimum 20 tons	Minimum 40 tons
Chicago	$ 9.80	--
St. Louis	9.00	--
Cleveland	11.20	--
Atlanta	10.40	--
New York	12.40	--
Boston	13.60	$ 13.00
Portland, Me.	13.60	13.00

Muriate of Potash c/l Rail

	Import Rates				Domestic Rates			
From New York to	Fertilizer Rate	Min.	Non-Fertilizer Rate	Min.	Fertilizer Rate	Min.	Non-Fertilizer Rate	Min.
Chicago	$6.80	20 T	$8.40	20 T	$6.80	20 T	$8.40	20 T
St. Louis	7.40	20 T	9.00	20 T	7.60	20 T	9.20	20 T
Atlanta	8.60	20 T	8.60	20 T	8.60	20 T	8.60	20 T
From New Orleans to								
Chicago	7.80	20 T	same		9.60	20 T	same	
St. Louis	7.80	20 T	same		8.60	20 T	same	
Atlanta	7.00	20 T	same		7.00	20 T	same	

Potassium Chloride
Minimum 40 Tons
Rail from Trona, California, to:

Chicago	$ 12.40
St. Louis	11.90
Atlanta	13.90
New York	14.40

Current Market Quotations

Ammonium sulphate, f.o.b. ports or ovens, per ton $28.00

Ammonium phosphate, f.o.b. works, 11% N
48% P_2O_5, bulk unit.....$1.20 and .70

Caustic potash, flake 88-92
Drums c/l, works..... .07
Liquor 45%..... .03-1/8

Chlorate of potash, crystals, kegs..... .09¼
Granulated, kegs..... .12
Powdered..... .08½

Muriate, domestic, all strengths, minimum 50% K_2O,
in bulk at ports, unit ton.....$ .535
In bags add $2.00 per ton
Super phosphate, Baltimore, $8.50 per ton run of
pile, $9.00 per ton guaranteed 16% material
Super phosphate, Atlanta, interior producing points 9.60
Super phosphate, 20%, f.o.b. cars Chicago..... 20.50
Sulphuric acid, 66%, f.o.b. tank cars, Garfield,
Utah, per ton..... 10.00
Coal tar f.o.b. tank cars plant per gallon..... .0475
(Estimated quotation received from the Barrett Co.)
Benzol, f.o.b. tank cars plant, per gallon..... .16
Zylol and toluol f.o.b. tank cars plant, per gallon .30
(The crude benzol will yield about 85% refined
benzol and about 15% zylol and toluol.)
Coking coal, quotation by Colorado Fuel & Iron Co.,
f.o.b. cars Trinidad, Colorado, per ton..... 2.00
(The freight rate is estimated at $5.50, making
the cost f.o.b. cars Green River, Wyoming.... 7.50
Coal, 3" mine run, f.o.b. cars Sunnyside, Utah, ton 2.10
(Estimated freight to Green River, $2.90, so
estimated cost, f.o.b. cars Green River..... 5.00

Analysis of Markets

East North Central and west North Central States:

This group includes the states of Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, Kansas, Nebraska, South Dakota, and North Dakota. These states consumed 893,967 tons of fertilizer in 1936. Statistics of 1934 showed the leading grade to be 2-12-6 (N, P_2O_5, K_2O) and it has been assumed that this grading applies to 1936. Therefore--

P_2O_5 consumed, tons annually	107,300
K_2O consumed, tons annually	53,650
Ratio $\frac{P_2O_5}{K_2O}$	2/1
Ratio $\frac{P_2O_5}{K_2O}$ in crude potassium metaphosphate, approx.	1.67/1
Tons of K_2O which can be supplied as crude potassium metaphosphate	53,650
Tons of P_2O_5 which can be supplied as crude potassium metaphosphate	89,400
Tons of 92% potassium metaphosphate to supply the entire market	155,500

The daily production of potassium metaphosphate in the proposed plant is 305 tons and its operation has been assumed for 330 days annually, the annual production, tons.....100.500
Assume that 30% of the market of the states in this group can be captured, giving rise to annual sales of potassium metaphosphate, tons..... 46,700
Percentage of total output sold in these states..... 46.4

The greater part of the fertilizer in these states is consumed in the Eastern section, principally in the states of Ohio, Indiana, and Michigan. Cleveland or Cincinnati should therefore be considered as the principal receiving point rather than Chicago or St. Louis. Sixteen percent super phosphate is worth about $14.50 per ton at this point or $.90 per unit, and muriate in bulk is worth about $.65 per unit. Of course, some fertilizer from Green River would be sold at Chicago and points west at higher unit prices and with less freight to charge from Green River, but by basing calculation upon Cleveland and Cincinnati delivery, the results will be conservative. The vast area of the western tier of these states still consumes but little fertilizer, although there has been evidenced a rather large percentage increase in consumption in recent years. Any increase in the use of fertilizer in this vast agricultural region including the states of Missouri, Kansas, Nebraska, Iowa, North Dakota, and South Dakota, would greatly benefit the proposed Green River fertilizer industry.

Using the above values:

Value of P_2O_5 in one ton 92% potassium metaphosphate at $.90 per unit	$ 51.80
Value of K_2O in one ton 92% potassium metaphosphate at $.65 per unit	22.45
Total value per ton of 2000 lbs	74.25
Estimated freight per ton to Cleveland and Cincinnati	9.75
Value 92% potassium metaphosphate at plant	$ 64.50

South Central States:

This region comprises the states of Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, and Texas. Their total consumption of fertilizer in 1936 was 1,151,065 tons and the leading grade of 1934 shows a ratio of P_2O_5/K_2O of about 8/5 or approximately that occurring in the crude potassium metaphosphate. Therefore—

P_2O_5 consumed annually, tons	92,000
K_2O consumed annually, tons	55,200
Tons of 92% potassium metaphosphate corresponding	160,000

Assume that 20% of the market is captured, or tons annually potassium metaphosphate	32,800
Percentage of total output sold in these markets	32.6
At present market value the unit P_2O_5 is worth in this territory approximately	$ .75
Approximate value unit K_2O	.65
Value P_2O_5 in one ton potassium metaphosphate	43.20
Value K_2O in one ton potassium metaphosphate	22.40
Total value per ton potassium metaphosphate	65.60
Estimated average freight	11.00
Value 92% potassium metaphosphate at plant	$ 54.60

North Atlantic States:

This group includes the states of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and Pennsylvania. Their total consumption of fertilizer in 1936 was 1,010,097 tons and the leading grade in 1934 was 4-8-7.

P_2O_5 consumed annually, tons	80,800
K_2O consumed annually, tons	70,800
Ratio P_2O_5/K_2O	1.14/1
Ratio P_2O_5/K_2O crude potassium metaphosphate	1.67/1
Tons P_2O_5 which can be supplied as crude 92% potassium metaphosphate	80,800
Tons K_2O which can be supplied as crude 92% potassium metaphosphate	48,500
Tons potassium metaphosphate to supply entire market	140,500

Assume that percentage of market captured is 15%, or

tons annually	21,000
Percentage of total output sold in these markets	20.9
At present market value unit P_2O_5 is worth in this territory approximately	$ .75
K_2O, approximately	.60
Value of P_2O_5 in one ton 92% potassium metaphosphate	43.20
Value of K_2O in one ton 92% potassium metaphosphate	20.70
Total value per ton	63.90
Estimated average freight rate	13.00
Value of 92% potassium metaphosphate at plant, ton	$ 50.90

South Atlantic States:

This group comprises the states of Deleware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Georgia, and Florida. Their total consumption in 1936 was 3,507,756 tons and the 1934 ratio P_2O_5/K_2O was about 8/5, or approximately that occuring in the crude potassium metaphosphate.

P_2O_5 consumed, tons	280,500
K_2O consumed, tons	168,000
Tons 92% potassium metaphosphate to supply the entire market	422,000
At present market values the unit P_2O_5 is worth in this territory approximately	$ .75
K_2O is worth approximately	.60
Value P_2O_5 in one ton 92% potassium metaphosphate	43.20
Value K_2O in one ton 92% potassium metaphosphate	20.70
Total value per ton	63.90
Estimated average freight	12.00
Value 92% potassium metaphosphate at plant per ton	$ 51.90

For the purpose of this estimate it will be assumed that no sales of fertilizer from Green River are made in the South Atlantic states.

The sales on the Pacific Coast are relatively small, and the amount of potash consumed is so small that it is not worth while counting upon any sales on the Pacific coast.

Summarizing, 46.5% of the sales of 92% potassium metaphosphate according to the above estimates will yield at the plant $64.50 per ton; 32.6%, $54.60 per ton; 20.9%, $50.90 per ton, or an average of $58.45 per ton at the plant.

Value of Annual Sales.

100,500 tons 92% potassium metaphosphate at the plant annually	$ 5,880,000.00
10 tons ammonium sulphate daily corresponding to 25 lbs. per ton of coal at $23.20 per ton	76,500.00
3,070 gallons per day benzol at average net return of $.18 per gallon for refined fractions	182,500.00
11,500 gallons per day coal tar at $.0475	180,262.00
7 long tons per day 24% ferro-phos. at $85.00 per ton	196,500.00
90 tons per day potassium chloride containing 62% K_2O at $28.90 per ton at plant	858,000.00
Soda ash, 10 tons per day at $25.00	82,500.00

The development of several of the quantities used in the above estimate will be found below.

Each of the four flow sheets described herewith will be considered separately as to sales, and after the summation of the several items 4% is deducted to cover general overhead and sales expense. This gives the following values for net annual sales:

Flow Sheet #1	$6,334,350.00
Flow Sheet #2	7,158,000.00
Flow Sheet #3	7,078,000.00
Flow Sheey #3A	7,078,000.00

Investment in Plant and Amortization Charge

No attempt will be made at this time to prepare a detailed estimate of the capital required, but reliance will be placed upon an approximation of $2.00 capital investment per annual dollar of net sales. Therefore--

The capital required in the several flow sheets is as follows:

Flow Sheet No.1.....	$12,668,700.00
Flow Sheet No.2.....	14,316,000.00
Flow Sheet No.3.....	14,157,600.00
Flow Sheet No.3A....	14.157,600.00

The fertilizer business is relatively stable and the trend in consumption is upward. Quoting from Fertilizer Consumption in the United States, 1937, page 5:

"The slight rise which has taken place in the total fertilizer tonnage in the period subsequent to 1910 has been due entirely to the increased use in the Middle west and west. As the soils in these newer farming regions become more depleted it seems likely that the use of plant food will increase more rapidly in the future than it has increased in the past."

Under the circumstances it seems advisable to use a long period of amortization, say twenty-five years, in which to return the investment.

$100.00 set out at interest of 4½% compounded annually is worth in 25 years.....	$ 300.00
The annuity which if set aside each year with 4½% interest compounded annually will produce $300.00 in 25 years is.....	6.73
Therefore--	
The required sinking fund to take care of interest and amortization under the assumed condition is.....	6.73%
Add for taxes and insurance.....	2 %
Total capital charges.....	8.73%

Annual capital charges:

Flow Sheet No. 1.....	$1,105,000.000
Flow Sheet No. 2.....	1,260,000.00
Flow Sheet No. 3.....	1,225,000.00
Flow Sheet No. 3A.....	1,225,000.00

ESTIMATED OPERATING COSTS

Flow Sheet No.1:

Stations Nos.1 to 4 incl.

1230 tons Wyomingite, mining, primary crushing and tramming to trackside bins, loading f.o.b. cars Superior, Wyoming, @ $.60 per ton.....$	738.00
Royalty to Union Pacific Railroad @ $.05 ton...	61.50

Station No. 5

Freight on Wyomingite, Superior to Green River, Wyoming, @ $.50 per ton.....	615.00

Station No. 6

In and out of Green River storage @ $.05 ton...	61.50

Station No. 7

According to Allis-Chalmers Mfg.Co., grinding of Wyomingite such as was found suitable for base exchange (R-10) can be accomplished with the expenditure of 4.5 kwh per ton. This power would be consumed continuously during the entire 24 hours and it would be supplied from a turbo-generator in the blast furnace plant. The operation of this turbo-generator would come under direct labor and maintenance charges covered elsewhere. Capital charges are grouped for the plant as a whole, therefore no charge is entered under this item or any subsequent items for continuous electrical energy. In this case:

Kwh required per day continuous power.....	3350
$2\frac{1}{2}$ lbs. steel balls at $.03.....$	55.80
Direct operating labor, six men.....	31.20

Maintenance cost is covered under general plant maintenance.

Station No. 8

Direct labor, 3 men @ $5.20.....$	15.60
Kwh continuous power per day.....	900

Stations Nos. 9 and 10

Direct labor, 3 men @ $5.20.....$	15.60
Continuous power required for turning autoclaves kwh per day.....	900

The autoclave batch to make 54.8 tons K_2O daily is made as follows:

Constituent of Batch	Pounds	Sp. H.
Soda well water	1,330,000	.912
wyomingite	1,488,000	.2
water	660,000	1.00
Return $NA_2CO_3H_2O$ (R-10)	305,000	.356
Total	3,783,000	
M. sp. h. of batch		.602

Before an autoclave is discharged it is blown down and the exhaust steam used to heat up a new discharge. The exhaust steam should heat the new discharge to 190° F. and live steam must be applied from 190° F. to 392° F. Therefore:

B.t.u. per hr. live steam,

$$\frac{3783000 \times 202 \times .602}{24} = \qquad 19,200,000$$

Estimated losses to outside, b.t.u. per hr..... 1,260,000

Total requirements for live steam at autoclaves, b.t.u. per hr..... 20,460,000

Heating starts at 190° F. and goes to 392° F.

Logarithmic mean temperature,

$$\frac{392 - 190}{2.3 \log_{10} \frac{392}{190}} = \qquad 280^\circ \text{ F.}$$

Steam will be provided at 250 lbs. gauge and 200° superheat.

Total heat per lb. of steam above 280° F.

Liquid.....129
Latent.....821.6
Superheat.....113.3

Total heat of steam, b.tu. per lb.....1063.9

Lbs. of steam required per hr. by autoclaves,

$$\frac{20460000}{1063.9} = \qquad 19,230$$

Stations Nos. 11 to 13 incl.

Direct operating labor, 6 men.....$ 31.20

Water going forward to the evaporators daily is estimated as follows:

From soda well water, 1,330,000 x .8824	1,176,000 lb
Added water.....	660,000 lb
Water for washing 17 tons KCl crystals..	34,000 lb.
Water for washing 12 tons $NA_2CO_3H_2O$ crystals	24,000 lb.
Total.....	1,894,000 lb.
Deduct water removed with potassium carbonate brine (R-10).....	155,000 lb.
Water evaporated.....	1,739,000 lb

Assume that 52.5% of this total is to be evaporated from 150° F. at 212° F. by the condensation of saturated steam at 40 lbs. gauge.

Heat to be imparted to accomplish this:

	B.t.u. per hour
Heat of liquid, $\frac{1799000 \times .525 \times 62}{24} =$	2,440,000
Heat of solids, $\frac{11422 \times 54.8 \times 62 \times .525 \times .25}{24} =$	405,000
Latent heat, $\frac{1739000 \times .525 \times 970.4}{24} =$	36,900,000
Total.....	39,745,000

Heat in steam at 40 lbs. gauge above 262°:

Liquid.....35
Latent.....919
Total.....944 b.t.u. per lb.

Lbs. of steam at 40 lbs. gauge required per hour,

$$\frac{39745000}{944} = 42,100$$

A small amount of continuous power will be required by the evaporators but this is not a large item.

Station No. 14

Both the $NA_2CO_3H_2O$ crystals and KCl crystals will be handled at this station. Because of small tonnage only one man will be required.

Direct labor.....$ 5.20

60 hp will be required on one shift to spin the centrifugals.

Cost of one shift power at $.01 per kwh..... 3.60

Stations Nos. 15 to 18 incl.

Direct labor, 2 operators on one shift at $5.20 10.40

Slack coal, 5 tons at $2.50..... 12.50

66° sulphuric acid at $15.00 per ton f.o.b. tank cars Green River.....120.00

Coke oven gas used in the conversion furnace is estimated at 5,500,000 b.t.u. per ton of monopotassium phosphate and approximately 37 tons monopotassium phosphate will be produced daily as a result of the operation of this furnace;

Heat required in coke over gas per day, b.t.u..204,000,000.

Stations Nos. 19 and 20.

It has been previously estimated (R-Tech. nical and Economic Summary) that the cost of production of phosphate rock in Georgetown Canyon at the rate of 743 tons daily is as follows:

Item	Per Day
Superintendent	$ 20.00
Foreman	8.00
3 shift bosses	20.00
2 blacksmiths	12.00
4 helpers	24.00
1 pipe man	8.00
1 electrician	8.00
3 compressor men	18.00
2 nippers	12.00
60 miners, shovelers, and timber men in stopes	300.00
60 miners, shovelers, and timber men for development work	300.00
23 trammers	115.00
Total	$845.00
Total direct labor per ton	1.136

For the purpose of this estimate the labor cost is placed at 60% of the total, making total cost per ton at mine.....$ 1.90

The ore will be trammed from the mine to the main line of the Union Pacific at Georgetown, Idaho, a distance of 8 miles at an estimated cost for labor and material, per ton.$ .13

Cost of ore in cars f.o.b.Geortown, Idaho, per ton.. 2.03
Freight to Green River, Wyoming, per ton..... 1.75
Cost laid down Green River, Wyoming, per ton..... 3.78
Per day for 609 tons at $3.78.....$ 2,300.00

Stations Nos. ~~22 and 23~~ 21
Direct labor, 2 men.....$ 10.40
Estimated one shift power..... 6.00

Stations Nos. 22 and 23.
Assume that all of the phosphate rock is sintered to improve its physical condition and to drive off fluorine. Assume that 6% of its weight of fine coke is used for this purpose. This coke would be provided by screening the coke from the by-product coke ovens and its cost will be covered under the next item.
Direct labor, 6 men.....$ 31.20
About 400 continuous hp will be required.
Kwh per day continuous power.....7170

Stations Nos. 24 to 26 incl., 39, 38a, 40.

A study was made of the manufacture of coke at Green River (R-2) in which Parr's laboratory, University of Illinois, Urbana, Illinois, and Koppers Co. assisted. It was found that the Parr process would provide a sound metallurgical coke of a mixture of 40% Sunnyside coal and 60% Rock Springs coal. A plant to produce 453 tons of blast furnace coke daily plus 36.5 tons of fine coke required for sintering would cost about $2,500,000, and the cost of the coke would be made up as follows:

	Cost per Ton of Coal
.6 tons of Rock Springs coal @ $2.50	$1.50
.4 tons of Sunnyside coal @ $5.00...	2.00
Conversion cost.....	1.85
Total operating debit per ton coal	5.35
Cost per ton of coke based upon a yield of 65%.....	8.34

In addition to the coke there will be produced per ton of coal approximately 12,000 cu.ft. of surplus gas having a gross heating value of 500 b.t.u.

Cost of coke daily, 8.34 x 489.5 =	$ 4,090.00
Cu.ft. of surplus gas per hour....	383,000
B.t.u. per hour of surplus gas....	191,500,000
Ammonium sulphate at 25 lbs. per ton of coal daily, tons.....	10
66° sulphuric acid required daily, tons	7.5

For cost of this tem see Station No.35.

Stations Nos. 27, 29 to 31 incl., 31a, 41, 41a, 41b, 42.

Ferro-Phosphorous:

The wyomingite contains 1.6% FeO and 4.1% Fe_2O_3. This corresponds to 4.12% Fe. Therefore:

Amount of iron daily in wyomingite, 486 x .0412 =	20 tons
Amount of iron daily in coke, 453 x .0077 =	3.5 "
The Fe content of the phosphate rock is very low and will not average over .35%.	
Amount of iron daily in phosphate rock, 609 x .0035 =.....	2.1 "
Total iron added daily to furnace.....	25.6 "

According to the recorded experiments an equivalent of 1.85% Fe of the charge except coke is lost in the slag. Therefore:

Iron lost in slag daily, 1062 x .0185 =	19.7 "
Net iron recovered as Ferro-phos.....	5.9 "
24% Ferro-phos. corresponding tons.....	7.76
Phosphorous with iron as Ferro-phos.....	1.86

The present consumption of ferro-phos. on the Pacific Coast is 300 to 400 long tons annually used in wire stock and the price is $93.00 per long ton f.o.b. San Francisco for the 24% grade with an adjustment of $3.00 per unit of P. About $85.00 per ton could be realized at Green River for ferro-phos. on this basis and the value of the daily production would be

$$7.76 \times 85 \times \frac{2000}{2240} = \ldots\ldots\ldots\ldots\ldots\ldots \$\ 589.00$$

Direct Labor:

Direct labor is taken at $1.93 per ton P_2O_5 (P-1), or per day..... 338.00

Power:

The principal power required is of course the continuous blowing power to supply the air blast to the furnace and the air for combustion to the stoves.

Assume--

Blast pressure at blower..... 16 lb. ga.
Stove air pressure at blower..... 8 " "

Blast Blower:

Carbon contained in coke per day, .8861 x 453 = 402 tons
Lbs. of carbon per min..... 557
Lbs. of air per min. required for combustion to CO 3200

It is required to deliver this air at 16 lbs. gauge at 6000 ft above sea level. Ingersoll-Rand have submitted a detailed proposal to supply this air from a direct connected turbo-blower set. This proposal has been figured two ways, namely: with a condensing turbine operating at 29" vacuum and a non-condensing turbine operating at 40 lbs. back pressure.

Steam required by turbine per hr. condensing.....30,800 lb.
Steam required by turbine per hr. non-condensing..89,800 "
BHP at blower coupling..... 3,600
The steam at 40 lb. gauge required by the evaporator is.....42,100

The indicated arrangement is therefore to use two turbo-blower sets for the blast, one non-condensing using 1700 BHP and the other condensing using 1900 BHP.

Therefore:

Steam required by non-condensing unit per hour....42,500 lb.
Steam required by condensing unit per hour.....16,250 "

Blower for Combustion Air to Stoves:

Heat required to heat 3200 lbs. of air per min from 60° F. to 2000° F., 3200 x 1940 x .25 = ...1,550,000 lb
If the stoves have an efficiency of 60%, b.tu. required in top gas to heat them is.....2,590,000

According to former calculations there are available in the blast furnace top gas 17,700 b.t.u. as heat of combustion of CO per lb. P_2O_5 and 3,000 b.t.u. as sensible heat. Therefore:

B.t.u. available per min. from the combustion of CO, $\frac{175 \times 2000 \times 17700}{1440}$ = ...	4,300,000
As sensible heat.....	728,000
Total.....	5,028,000
Surplus top gas b.t.u. per min., 5028000 - 2590000 = ...	2,438,000
Lbs. CO burned per min. in stoves, $\frac{2590000}{4370}$ = ...	593
Air required for combustion.....	1460
Add 10%.....	146
Total air required by stoves, lbs. per min.....	1606

It is required to deliever this air at 8 lb. gauge at 6000 ft above sea level.

According to the Ingersoll-Rand proposal, a condensing turbo-blower with steam at 250 lbs. pressure and 200° super heat will require at the turbine, lbs. per hr..... 9900

BHP at ~~power~~ blower coupling..... 1050

Continuous H.P. Required in Plant at Green River Other than for the Blast Furnace.

The total which is given below is only approximate.

Station	Continuous H.P.
7	200
8	50
9, 10	50
11	50
22, 23	400
24 to 26 incl., 39, 39a, 40	250
27, 29 to 31 incl., 31a	200
28	25
33, 33a, 33b	25
36a	100
43a, 44, 45, 46	250
Misc. and unaccounted for	750
Total	2350

Lbs. of steam required per hour in condensing turbine to provide continuous plant power.....22,000

Summary Requirements of Steam at
250 lbs. Pressure and 200° Super Heat:

	Lbs. per hr.
Non-condensing blast unit	42,400
Condensing blast unit	16,250
Condensing stove unit	9,900
Condensing plant unit	22,000
Add 15% for auxiliaries	13,600
Autoclaves	19,230
Total	123,380
Deduct steam from phosphorous boiler 29, (See below)	40,640
Net live steam required per hr. from burning of gas	82,740
B.t.u. per hr., 1143.9 x 82740 =	94,600,000
B.t.u. per hr. required in gas at a boiler efficiency of 85%	111,500,000

Phosphorous Boiler:

In boiler 29 the phosphorous is burned to P_2O_5.

Lbs. P per min., $\frac{175 \times 2000}{1440} \times \frac{62.06}{142.06}$ = ... 106

Heat of combustion 1 lb. P to P_2O_5, b.t.u..... 10,570
B.t.u. per min from combustion of P..... 1,120,000
Lbs. of steam per hr. with a boiler efficiency of 80%, $\frac{1120000 \times .80 \times 60}{1143.9}$ = ... 47,000

All of the P_2O_5 from the boiler passes to the Cottrell precipitator where it is hydrolyzed with steam. Each lb. of P requires about one lb. of steam to make a fairly liquid acid. Therefore:

Lbs. of steam required per hr. for this purpose..6,360
Suprlus steam from phosphorous boiler per hr....40,640

The design of the phosphorous boiler 29, while seemingly entirely feasible, requires some study because of the presence of P_2O_5 fume in the gas. Probably the P_2O_5 is not corrosive if water is absent, and on this account it would probably be advisable to use a dry blast. It may also be necessary to make this boiler from stainless steel.

Station No. 28.

The continuous production of 5 soda wells will be required.
Direct labor.....$ 15.60
Continuous h.p..... 25

Stations Nos. 32, 33, 33a, 33b.

These stations are concerned with preparing and shipping 10 tons soda ash daily. A lump cost of $5.00 per ton will be estimated to cover direct cost of operation.
Per day..... $ 50.00

Station No. 35.

The requirements for sulphuric acid for Station No. 15 have already been covered. In addition there will be required for the manufacture of ammonium sulphate 7.5 tons 66° acid daily at $15.00..... $ 112.50

Stations Nos. 36, 36a, 36b, 37.

The cost of limestone f.o.b. cars Green River is taken at $3.90 per ton (R-Technical and Economic Summary). The steps involved in these stations can be carried out in connection with other parts of the plant and a lump sum of $5.00 per ton will be provided to cover direct operating cost, per day..... 60.00

Station No. 43.

In this neutralizing tank there will be daily 350 tons KH_2PO_4 as a 25% solution requiring 700 tons of water.

water added in tank 16.....	20 tons	
water in potassium carbonate brine.....	80 "	
water added with acid.....	105 "	
Total.....	205 "	
water to be added in tank 43.....		495 tons
Direct labor, 3 men.....		$ 15.60

Stations Nos. 43a, 44 to 46 incl.

water to be evaporated per hr., $\frac{700 \times 2000}{24}$ = 58,400 lbs.

Total heat of steam per lb. at 5 lbs. absolute pressure..... 1,130.5

B.t.u. per hr. to be supplied in fuel at a drying efficiency of 50%, $\frac{58400 \times 1130.5}{.5}$ = 132,500,000

Direct labor:

3 drier men.....	$ 15.60
3 storage men.....	15.60
6 packing men.....	31.20
6 shipping men.....	31.20
Total.....	$ 93.60

Heat Balance of Flow Sheet No.1
Showing Total Heat Available in Surplus
Top Gas and Coke Oven Gas and Its Utilization

Item	Debit B.t.u. per hr.	Credit B.t.u. per hr.
Surplus coke oven gas	192,000,000	
Surplus blast furnace top gas	146,300,000	
Required for the generation of steam		111,500,000
Required in KCl conversion furnace		8,500,000
Required for evaporating solution of monopotassium phosphate		132,500,000
Surplus		85,800,000
	338,300,000	338,300,000

Pounds of steam per hour at 250 lbs. gauge and 250° superheat which can be generated by surplus gas.....63,800

Size of continuous power plant which can be operated, kw..... 4,570

Estimated Annual Expense

Flow Sheet No.1:

330 days annual direct operation.

Station	Annual Expense
Nos.1 to 7 incl. wyomingite. All charges except indirect.....	$ 516,000
No.8. Direct operating labor.....	5,150
Nos.9 and 10. Direct operating labor.....	5,150
No.11. Direct operating labor.....	10,300
No.14. Direct labor and one shift power..	2,900
Nos.15 to 18 incl. Direct operating labor	3,435
Coal.....	4,125
Sulphuric acid.....	39,600
Nos.19 and 20. Phosphate rock.....	758,000
No.21. Direct operation and one shift power.....	5,410
Nos.22 and 23. Direct operating labor....	10,300
Nos.24, 25, 26, 39, 39a, 40. All charges except indirect.....	1,350,000
Nos.27, 29, 30, 31, 31a, 41, 41a, 41b, 42, Direct operating labor.....	111,500
No.28. Direct operating labor.....	5,150
Nos.33, 33a, 33b. All charges except indirect.....	16,500
No.35. Sulphuric acid.....	37,100
Nos.36, 36a, 37, 36b. All charges except indirect.....	19,800
No.43. Direct operating labor.....	5,150
Nos.43a, 44, 45, 46. Direct operating labor.....	30,900
Plant maintenance, $1,000 per day.....	365,000
Factory overhead:	
General superintendent...$27.50 per day	
6 foremen..... 60.00 " "	
Office and clerical expense.....100.00 " "	
Chief chemist..... 20.00 " "	
12 asst.chemists..... 66.00 " "	
Total.....$273.50 " "	
Annual charge.....	99,700
Capital Charges.....	1,105,000
Total annual expense.....	$ 4,506,170
Deduct credit for surplus gas at $.05 per million b.t.u.....	34,000
Net annual expense.....	$ 4,472,170
Net value annual sales.....	6,334,350
Net profit before Federal taxes.....	1,862,180
Per cent net return on investment after all charges, before Federal taxes.....	14.7%

Estimated Operating Costs
Flow Sheet No.2

Stations Nos. 1 to 4 incl.
2011 tons wyomingite, mining and primary crushing, tramming to trackside bin and loading f.o.b. cars Superior @ $.60.....$ 1,207.00
Royalty to Union Pacific..... 100.00

Station No. 5. Freight Superior to Green River..... 1,005.00
Station No. 6. In and out of Green River storage..... 100.00
Station No. 7. Grinding 1525 tons daily for base exchange:
Steel balls.....$114.50
Direct labor..... 62.40
Total..... 176.90
Continuous power required in grinding, hp..... 383
Station No. 8. Same as Flow Sheet No.1.....$ 15.60
Stations Nos. 9 and 10. Continous power, hp..... 100
B.t.u. per hr. steam to autoclaves, 39,300,000
Losses..... 2,530,000
Total..... 41,830,000
Lbs. of steam required per hr. by autoclaves.. 39,600
Stations Nos.11, 12, 13. Direct labor.....$ 31.20
Water going forward to evaporators daily:
In soda line which handles 68.5 tons K_2O daily instead of 54.8 tons as in Flow Sheet No.1.....2,175,000 lb.
Steam required per hr. at 40 lbs.gauge.. 52,600 lb.
In salt line which handles 42.3 tons K_2O daily:
Water added, lbs.....1,415.000
Water for washing KCl crystals, lbs.. 136,000
Total.....1,651,000 lb.

Assume the same general conditions in the salt line as in Flow Sheet No.1 with backward flow triple effect evaporation and assume that 35% of the evaporation takes place in the first effect.

Heat to be imparted in first effect:
Heat of liquid, $\frac{1651000 \times .35 \times 62}{24}$ = ...1,495,000
Heat of solids, approximate..... 250,000
Latent heat, $\frac{1651000 \times .35 \times 970.4}{24}$ = ...23,400,000
Total.....25,145,000
Lbs. of steam at 40 lb. gauge required per hr., $\frac{25145000}{944}$ = ... 26,650
Total steam required per hr. by evaporators..... 79,250

Station No. 14.
The centrifugals will handle 12 tons $NA_2CO_3H_2O$ and 90 tons KCl daily. One man can handle two 60" machines taking 1000 lbs. each every 10 min.
Capacity each machine in 24 hrs.....72 tons
Therefore two machines are more than ample.
Direct labor.....$ 15.60
Continuous hp..... 100

Stations Nos. 19 and 20. Phosphate rock same as Flow Sheet No.1.....$2,300.00
Station 21. Direct labor same as Flow Sheet No.1..... 10.40
One shift power, hp 100..... 6.00
Stations Nos. 22 and 23. Direct labor..... 31.30
Continuous power, hp..... 400
Stations Nos. 24, 25, 26, 26a, 26b, 26c, 26d, 26e, 39, 39a, 40. Sames as Flow Sheet No.1.....$4,090.00
Stations Nos. 27, 29, 30, 31, 31a, 41, 41a, 41b, 42. Direct labor same as Flow Sheet No. 1..... 338.00
Station No. 28. Direct labor..... 15.60
Continuous hp..... ,25
Stations Nos. 33, 33a, 33b. Sames as Flow Sheet No.1.$ 50.00
Station No. 35. Same as Flow Sheet No.1..... 112.50
Station No. 43. Direct labor..... 15.60
Water to be added daily..... 495 tons
Stations Nos. 43a, 44, 45, 46. Water to be evaporated same as Flow Sheet No.1, lbs. per hr..... 58,400
B.t.u. per hr. required in gas same as Flow Sheet No. 1, ...132,500,000
Direct labor, same as Flow Sheet No.1.....$ 93.60
Stations Nos. 48, 49, 50. Direct labor..... 31.20
Station No. 53. Salt, 54 tons @ 5.50..... 358.00

Estimate of Continuous HP Required at Green River Plant:

Station	HP
7	383
8	50
9 and 10	100
11	100
14	100
22 and 23	400
24, 25, 26, 39, 39a, 40	250
27, 29, 30, 31, 31a	200
28	25
33, 33a, 33b	25
43a, 44, 45, 46	250
Misc. and unaccounted for	650
Total	2533

This total is quite approximate and does not include the power required for the blast furnace blast, nor the air for combustion at the stoves.

Lbs. of steam required per hr. in condensing turbine, 23,700

Summary of Requirements of Steam at 250 lbs.Pressure and 200° Super Heat

In Flow Sheet No.2 the multiple effect evaporators require 79,250 lb. of steam per hour. As the steam used by the blast turbo-blower operating non-condensing (See Flow Sheet No.1) is 89,800 lbs. per hour, it will be close enough for this estimate to assume that all of the blast power will be provided by a non-condensing turbine. The summary follows:

Item	Lbs.per Hr.
Non-condensing blast unit	89,800
Condensing stove unit	9,900
Condensing plant unit	23,700
Add 15% for auxiliaries	18,500
Autoclaves	39,600
Total	181,500
Deduct steam generated by phosphorous boiler, lbs.per hr	40,640
Net live steam required, lbs.per hr	140,860
B.t.u. per hr. required in gas at a boiler efficiency of 85%	189,500,000
B.t.u. per hr. in live steam, 1143.9 x 140860 =	161,000,000

Heat Balance of Flow Sheet No.2
Showing Total Heat Available in Surplus
Top Gas and Coke Oven Gas and Its Utilization

Item	Debit B.t.u. per hr.	Credit B.t.u. per hr.
Surplus coke oven gas	192,000,000	
Surplus blast furnace top gas	146,300,000	
Required for generating steam		189,500,000
Required for evaporating solution of monopotassium phosphate		132,500,000
Surplus		16,300,000
	338,300,000	338,300,000

Estimated Annual Expense

Flow Sheet No.2:
330 days annual direct operation.

Station	Annual Expense
Nos.1 to 7 incl. Wyomingite. All charges except indirect.....	$ 854,000
Nos.8 to 14 incl. See Flow Sheet No.1....	23,500
Nos. 19 and 20. Phosphate rock. All charges except indirect.....	758,000
Stations Nos. 21 to 26 incl., 39, 39a, 40, 27, 29, 30, 31, 31a, 41,41a, 41b, 42, 28, 33, 33a, 33b, 35, 43 to 46 incl., 43a. Same as Flow Sheet No.1.....	1,572,010
Stations Nos.48, 49, 50. Direct operating labor.....	10,300
Station No.53. Salt.....	118,000
Maintenance for 365 days @ $1,070.00 daily	390,000
Factory overhead, 365 days @ $300.00 daily	109.700
Capital charges.....	1,260,000
Total annual expense.....	$ ~~5,079,060~~ 5,085,510
Deduct credit for surplus gas @ $.05 per million b.t.u.....	6,450
Net annual expense.....	$ 5,079,060
Net value annual sales.....	7,158,000
Net profit before Federal taxes.....	2,078,940
Per cent net return on investment after all charges except Federal taxes.....	14.5%
Production of KCl annually containing 62% K_2O, tons.....	29,700
Extra cost of Flow Sheet No.2 as compared to Flow Sheet No.1 in which no KCl is produced.....	$ 606,000
Additional cost per ton KCl produced in Flow Sheet No. 2.....	20.40
Cost per unit K_2O.....	.329

Estimated Operating Costs
Flow Sheet No. 3

Stations Nos. 1 to 7 incl. Wyomingite. Same as Flow Sheet No. 2.....$		2,588.90
Stations Nos. 8 to 10 incl. Same as Flow Sheet No.2		31.20
Stations Nos.11 to 13 incl. Same as Flow Sheet No.2		31.20
water going forward daily in salt line:		
water added.....	3,710,000 lbs.	
water for washing 179 KCl crystals.....	358,000 lbs.	
Total.....	4,068,000 lbs.	
Heat to be imparted in first effect of triple effect evaporators:		
Heat of liquid, $\frac{4068000 \times .35 \times 62}{24}$ =	3,670,000 b.t.u. per hr.	
Heat of solids, approximate.....	650,000 "	
Latent heat, $\frac{4068000 \times .35 \times 970.4}{24}$ =	57,600,000 "	
Total.....	61,920,000 "	
Station No.14. The centrifugals will handle 180 tons KCl crystals daily.		
Direct labor.....$		31.20
Continuous power, hp.....		200
Stations Nos. 15 to 18 incl.		
Direct labor, 2 operators, 3 shifts.....$		31.20
Coal, 25 tons @ $2.50.....		62.50
40 tons of 66° sulphuric acid is required altogether, of which it will be assumed that 4 tons is purchased @ $15.00.....		60.00
And 36 tons is made from by-product SO_2 at a manufacturing cost of $2.50 per ton.....		90.00
Stations Nos.19 and 20. Phosphate rock. Same as Flow Sheet No.2.....		2,300.00
Station No.21. Same as Flow Sheet No. 2.....		16.40
Stations Nos. 22 and 23. Same as Flow Sheet No.2		
Direct labor.....		31.20
Continuous power, hp.....		400
Stations Nos. 24, 25, 26, 26a, 26b, 26d, 26e, 39, 40, 39a. Same as Flow Sheet No.2.....$		4,090.00
Stations Nos. 27, 29, 30, 31, 31a, 41, 41a, 41b, 42. Same as Flow Sheet No. 2.....		338.00
Station No. 35. Same as Flow Sheet No. 2.....		112.50
Station No. 36. Limestone, 61.5 tons @ $3.40.....		209.00
Station No, 43. Same as Flow Sheet No.2.....		15.60
Stations Nos. 48 to 50 incl. Same as Flow Sheet No.2		31.20
Station No.53. Salt, 144 tons @ $5.50.....		792.00

Estimate of Continuous HP Required at Green River Plant:

Station	HP
7	383
8, 9, 10	150
11	100
14	200
22 and 23	400
24, 25, 26, 39, 39a, 40	250
27, 29, 30, 31, 31a	200
28	25
33, 33a, 33b	25
43a, 44, 45, 46	250
Misc. and unaccounted for	650
Total	2633

This total is quite approximate and does not include the power required for the blast furnace blast, nor air for combustion for the stoves.

Lbs. of steam required per hr. in condensing turbine, 24,600.

Summary of Requirements of Steam at 250 lbs. Pressure and 200° Super Heat:

Although it has been estimated that the multiple effect evaporators in Flow Sheet No. 3 will take only 65,600 lbs. of steam per hour at 40 lbs gauge, it will be sufficiently accurate for the purpose of this estimate to assume that the blast turbo-blower will operate non-condensing and that all of the 89,800 lbs. of steam per hour which it will provide at 40 lbs. gauge will be used in the evaporators. The summary follows:

Item	Lbs. per Hr.	
Non-condensing blast unit	89,800	
Condensing stove unit	9,900	
Condensing plant unit	24,600	
Allowance for auxiliaries	18,650	
Autoclaves	39,600	
Total	182,550	
Deduct steam generated by phosphorous boiler, lbs. per hr.	40,640	
Net live steam requirements from burning fuel	141,910	
B.t.u. per hr., 1143.9 x 141,910 =		162,000,000
B.t.u. per hr. required in gas at a boiler efficiency of 85%		190,500,000

Heat Balance of Flow Sheet No. 3
Showing Total Heat Available in Surplus
Top Gas and Coke Oven Gas and Its Utilization

Item	Debit B.t.u. per hr.	Credit B.t.u. per hr.
Surplus coke oven gas	192,000,000	
Surplus blast furnace top gas	146,300,000	
Required for generating steam		190,500,000
Required in furnaces for converting KCl to phosphate		42,500,000
Required for evaporating solution of monopotassium phosphate		132,500,000
Deficiency of fuel	27,200,000	
	365,000,000	365,000,000

This deficiency of heat can be made up by purchase of natural gas at approximately $.05 per million b.t.u., or per day.....$ 32.60

Estimated Annual Expense

Flow Sheet No. 3:

330 days annual direct operation.

Station	Annual Expense
Nos.1 to 7 incl. Wyomingite. All charges except indirect.....	$ 854,000
Nos.8, 9, 10. Direct operating labor.....	10,300
Nos.11, 12, 13. Direct operating labor....	10,300
No. 14. Direct operating labor.....	10,300
Nos. 19 and 20. Phosphate rock. All charges except indirect.....	759,000
Nos. 15 to 18 incl. Direct operating labor	10,300
Coal.....	20,750
Sulphuric acid.....	49,500
No.21. Direct operating labor and one shift power.....	5,410
Nos.22 and 23. Direct operating labor.....	10,500
Nos.24, 25, 26, 26a, 26b, 26c, 26d, 26e, 39a, 40. Same as Flow Sheet No.2.....	1,350,000
Nos. 27 to 31 incl., 31a, 41, 41a, 41b. Direct operating labor.....	111,500
No.35.....	37,100
No.36.....	69,000
No.43. Direct operating labor.....	5,150
Nos.43a to 46 incl. Direct operating labor	30,900
Nos.48, 49, 50. Direct operating labor...	10,300
No.53. Salt.....	261,000
Fuel deficiency.....	10,750
Maintenance. Same as Flow Sheet No.2.....	390,000
Factory overhead. Same as Flow Sheet No.2.	109,700
Capital charges.....	1,225,000
Total annual expense.....	$ 5,360,560
Net profit before Federal taxes.....	1,718,240
Net value of annual sales.....	$ 7,078,800
Per cent return on investment after all charges except Federal taxes.....	12.15%

Estimated Operating Cost
Flow Sheet No.3A

Flow Sheet No. 3A is the same as Flow Sheet No. 3 except that Stations Nos. 54 to 60, incl., are substituted for Stations Nos. 15 to 18, incl. No detailed comparison can yet be made, but if all other charges are the same, there will be saved annually the following items by the use of Flow Sheet No.3A as compared with Flow Sheet No.3.

Purchased and manufactured sulphuric acid...	$ 49,500
Coal.....	20,750
Additional surplus fuel which is saved (See below.).....	41,700
Total annual saving effected by Flow Sheet No.3A as compared with Flow Sheet No.3....	$ 111,950

Heat Balance of Flow Sheet No.3A
Showing Total Heat Available in Surplus
Top Gas and Coke Oven Gas and Its Utilization

Item	Debit B.t.u. per hr.	Credit B.t.u.per hr.
Surplus coke oven gas	192,000,000	
Surplus blast furnace top gas	146,300,000	
Required in furnace for converting KCl to potassium metaphosphate - Assume same as in Flow Sheet No.3		42,500,000
Required for generating steam		190,500,000
Surplus		105,300,000
	338,300,000	338,300,000

The surplus fuel at a value of $.05 per million b.t.u. is worth, per day..... $ 126.50
Annual value.....41,700.00
This fuel would be capable of generating continuous power amounting to, kw..... 7,500

Annual expense Flow Sheet No. 3A.....	$ 5,248,610.00
Net value annual sales.....	7,078,800.00
Net profit before Federal taxes.....	1,830,190.00
Per cent of net return on investment after all charges except Federal taxes.....	12.9%

Flow Sheet No. 3A possesses advantages not shown by this approximate comparison in that the cost of establishing a by-product sulphuric acid plant is eliminated.

Other By-Products or

Correlated Industries

Potassium chloride can be electrolyzed with cheaply available electric power to produce caustic potash and chlorine, and the latter may be utilized in the Liebig process to make potassium chlorate; or the latter salt may be produced directly from potassium chloride in special electrolytic cells. Sufficient potassium chloride would be produced in Flow Sheets Nos. 2, 3, and 3A to make all of the cautic potash and chlorate of potash now used in the United States, worth approximately $3,000,000 annually. Thus the money value of the potassium chloride which would be utilized would be increased by processing almost four to one.

In Flow Sheet No.3A there would be produced daily about twenty tons chlorine as hydrochloric acid. The latter can be readily oxidized to chlorine with nitric acid by modern processes. The electrolysis of all of the KCl produced would yield about forty-two tons of chlorine and about twenty-five tons of this would probably be commercially available. Thus about forty-five tons daily chlorine would be available and it would be interesting to consider the possibilities of this as the basis of an industry for the production of synthetic chemicals from the available hydro-carbon resources; for example, coke oven gas, top gas, cheap natural gas as well as the liquid by-products of the coke ovens.

FURTHER COMMENT ON FLOW SHEET NO. 1

Net annual expense (See page 26.).....$ 4,472,000.00

Annual net value of by-products;

Ammonium sulphate.....	$ 73,500.00	
Benzol.....	175,000.00	
Coal tar.....	173,000.00	
Ferro-phos.....	188,700.00	
Soda ash.....	79,300.00	
Total.....		689,500.00

Net annual expense, after deducting sales value of by-products other than potash..... 3,782,500.00

Same per ton 92% potassium metaphosphate, f.o.b.plant 37.65

Average cost per unit plant food, f.o.b. plant..... .4090

Taking the value of K_2O at $.329 per unit, its approximate cost of production (See page 31.): Total annual value of 34,650 tons K_2O..... 1,140,000.00

Cost of producing 57,700 tons P_2O_5 at the plant, after deducting sales value of all by-products except potash, and cost value of latter..... .458

FLOW SHEET NO. 4

Flow Sheet No. 4 is Flow Sheet No. 1 after being stripped of all steps except those required to produce potash bearing phosphoric acid.

Referring to Page 26, the following items would be deducted from the annual expenses applicable to Flow Sheet No. 1:

Items 1 to 7	$ 312,000	
Item 8	5,150	
Items 9 and 10	5,150	
Item 11	10,300	
Item 14	2,900	
Items 15 to 18	3,435	
Items 15 to 18	4,125	
Items 33, 33a, 33b	39,600	
Items 36, 36a, 36b, 37	19,800	
Item 43	5,150	
Items 43a, 44, 45, 46	30,900	
15% of maintenance charges	54,700	
15% of capital charges	165,700	
15% of plant overhead	15,000	
Total		$ 690,410

Annual expenses applicable to Flow Sheet No. 4:

$ 4,472,170
- 690,410 = 3,781,760

Annual value of by-products, other than potash:

Ammonium sulphate, benzol, coal tar, ferro-phos., same as above 610,200

Net annual expense, after deducting sales value of by-products other than potash 3,171,560

Plant food produced:

P_2O_5 ..... 57,700 tons
By-product K_2O 16,550
Tons annually 74,250

Average cost of production at the plant, per unit of plant food ..... $ .4275

Value of by-product K_2O taken as above at estimated cost for production of $ .329 per unit ..... $ 533,000

Annual expense after deduction of all by-products, including potash, the latter being taken at cost .. $ 2,638,000

Cost per unit P_2O_5 at the plant ..... $ .457

Both Flow Sheets Nos. 1 and 4 show a net cost of production of P_2O_5 at the plant of about $ .46 per unit. This is calculated on a conservative basis by deducting in each case only $ .3290 per unit K_2O, which is estimated to be its actual cost of production (See page 31.). It was estimated (See page 14.) that the sales value of the unit K_2O at the plant is $ .4660. If this value had been deducted instead of the cost value, the cost of the unit P_2O_5 at the plant would have come out $ .416.

FLOW SHEET NO. 4A

This flow sheet covers the combination of the potash bearing phosphoric acid with phosphate rock to produce a potash bearing treble superphosphate.

In order to arrive at a preliminary estimate of the amount of phosphate rock required to neutralize the acid, it will be assumed that the western phosphate rock which will be utilized for this purpose will have the following analysis:

P_2O_5	30.2
CaO	48.2
MgO	.98
Al_2O_3	1.1
SiO_2	4.2
Na_2O	.65
K_2O	.33
F	3.5
CO_2	3.7

When this rock is combined with the phosphoric acid it will be assumed that all of the P_2O_5 in the rock will be combined as follows:

(1) Mono calcium phosphate, $CaH_4\ P_2O_8H_2O$, containing 22.2% CaO and 56.3% P_2O_5.

The MgO will be figured as its equivalent CaO.

(2) $AlPO_4$ containing 41.7% Al_2O_3 and 58.4% P_2O_5.

(3) NaH_2PO_4 containing 25.8% Na_2O and 59.2% P_2O_5.

KH_2PO_4 containing 34.6% K_2O and 52.2% P_2O_5.

In 100 lbs. of phosphate rock after treatment the following amounts of P_2O_5 are accounted for by bases other than CaO:

By Al_2O_3	1.54 lbs.
By Na_2O	1.49 "
By K_2O	.5 "
Total	3.53 "

This leaves 26.67 lbs., which combines with 10.5 lbs. CaO as mono calcium phosphate, leaving 37.7 lbs. CaO as such, plus 1.37 equivalent of MgO, or 39.1 lbs. total to combine with 99 lbs. P_2O_5 to form mono calcium phosphate.

Total P_2O_5 combined as $CaH_4P_2O_8H_2O$ .....125.67 lbs.

As NaH_2PO_4 ..... 1.49 "

As KH_2PO_4..... .5 "

Total available P_2O_5.....127.66 "

This will be contained in the following material:

$CaH_4P_2O_8H_2O$ .....223 lbs.

NaH_2PO_4 ..... 5.8 "

KH_2PO_4..... 1.4 "

$AlPO_4$ ..... 3.7 "

SiO_2 ..... 4.2 "

Total.....238.1 "

Theoretical maximum percentage available P_2O_5

$$\frac{127.66}{238.1} \times 100 = \ldots\ldots\ldots\ldots\ldots\ldots 53.7$$

But, the actual percentage available is only about 45. The above amount of P_2O_5 must therefore occur in 284 lbs. of material, or 46 lbs. more than have just been estimated.

For the purpose of this calculation it will be assumed, although this is not strictly true, that the extra 46 lbs. is added as surplus phosphate rock in which the P_2O_5 content does not become available. Therefore there are combined 146 tons of phosphate rock with 99 tons P_2O_5, as acid to form 284 tons of treble superphosphate containing 45% available P_2O_5.

If 16,550 tons by-product K_2O produced with the blast furnace acid is assumed to be combined with P_2O_5 as KH_2PO_4, it will account for 25,100 tons P_2O_5, leaving 32,600 tons which will be combined with 48,100 tons phosphate rock. The final product will be as follows:

47,900 tons KH_2PO_4 containing 16,550 tons K_2O and 25,100 tons P_2O_5.

93,500 tons treble superphosphate containing 42,100 tons P_2O_5.

Total product.....141,400 tons
Total P_2O_5..... 67,200 "
Total K_2O..... 16,550 "

Approximate analysis of product:

K_2O	11.7%
Available P_2O_5	47.5%
Total available and water soluble	59.2%

An estimate of the cost per unit P_2O_5 at the plant can now be made.

Annual expense Flow Sheet No. 4 given above, after deducting the sales value of by-products other than K_2O and the cost value of K_2O	$ 2,638,000
Cost of 48,100 tons phosphate rock, delivered at plant at $3.78	182,000
Total estimate for operating and maintenance for combining acid and phosphate rock, storing and shipping same in bulk at $1.50 per ton	212,000
Fixed charges based upon estimate of the investment in the mixing plant of $1,000,000	87,000
Net annual expense	3,119,000
Cost per unit P_2O_5 at the plant	$ .464

CONCLUSIONS AS TO THE COST OF THE UNIT P_2O_5 AT THE PLANT

The above analysis shows that whether the product is shipped as potassium metaphosphate or as potash bearing treble superphosphate, the estimated cost for producing the unit P_2O_5 at the plant is about the same, namely approximately $.46 per unit.

But the concentration of potassium metaphosphate is a minimum of 92% against about 59% for the potash bearing treble superphosphate. There may be good reasons for producing at least some of the latter to meet the demands of the trade; therefore in what follows, analysis will be made of the net sales return to be derived at the plant on shipments into the several distficts already analyzed on Pages 11 to 13.

East North Central and west North Central States:

Value of P_2O_5 at $.90 per unit ton of product, .475 x 90	$ 42.80
Value of K_2O at $.65 per unit, .117 x 65	7.60
Total value.....	$ 50.40
Deduct freight.....	9.75
Value at plant after deducting freight.....	$ 40.65 per ton

South Central States:

Value of P_2O_5 per ton product, .475 x 75	$ 35.70
Value K_2O, .117 x 65	7.60
Total value.....	$ 43.30
Deduct freight.....	11.00
Value at plant after deducting freight.....	$ 32.30 per ton

North Atlantic States:

Value of P_2O_5 per ton of product.....	$ 35.76
Value of K_2O per ton of product.....	7.02
Total value.....	$ 42.78
Deduct freight.....	13.00
Value at plant after deducting freight.....	$ 29.78

South Atlantic States:

Value at plant..... $ 30.78

It will be assumed, to parallel the former calculations, that all of the product will be sold as follows:

West North Central and East North Central, 46.5% at $40.65.....	$ 18.90
South Central, 32.6% at $32.30.....	10.53
North Atlantic, 20.9% at $29.78.....	6.22
Average rate at the plant, per ton.....	$ 35.65

As before, it is assumed that none of the product will be sold in the South Atlantic States, although a considerable amount could be. Also, some of this product could be sold on the Pacific Coast because of the low content of potash. Pacific Coast sales would bring a relatively high return at the plant.

Annual return from sales:

141,400 tons potash bearing treble superphosphate containing 11.7% K_2O and 47.5% available P_2O_5, at $35.65.....		$ 5,030,000
Ammonium sulphate.....	$ 76,500	
Benzol.....	182,500	
Coal tar.....	180,262	
Ferro-phos.....	196,500	
Total.....		$ 635,762
Total return.....		$ 5,665,762
Deduct 4% for general overhead and sales expense, giving net value of annual sales at plant.....		$ 5,440,000

Estimated Annual Expense

Flow Sheet No. 4A:

330 days annual direct operation.

This follows the estimate for Flow Sheet No.1(page 26), with appropriate deductions because of the omission of the base exchange and potassium metaphosphate plants and appropriate additions on account of the manufacture of the treble superphosphate.

Item	Annual Expense
Wyomingite used as flux	$ 204,000
Phosphate rock	940,000
Item 21	5,410
Items 22 and 23	10,300
Coke	1,350,000
Direct labor at blast furnace	111,500
Sulphuric acid	37,100
Cost of making treble superphosphate	212,000
Plant maintenance	325,000
Plant overhead	85,000
Capital charges	1,027,000
Total annual expense	$ 4,307,310
Deduct gas credit	34,000
Net annual operating expense	$ 4,273,310
Net value annual sales	5,440,000
Net profit	1,166,690

If the criteria of $2.00 per dollar of net sales had been adhered to to cover the total investment, this latter would have been $10,880,000, but it has been taken somewhat higher than this, namely $11,750,000 because of the greater bulk of material to be handled, due to the lower concentration of the product; therefore net return on investment, before Federal taxes, is 9.92%

This is somewhat less than any of the estimates for potassium metaphosphate, in spite of the approximately same cost per unit P_2O_5 at the plant, and this is due largely to higher freight rates per unit of plant food on the potash bearing treble superphosphate. The result would be improved if a practical and inexpensive way could be found for converting the potash bearing treble superphosphate into a mixture of potassium and calcium metaphosphate.

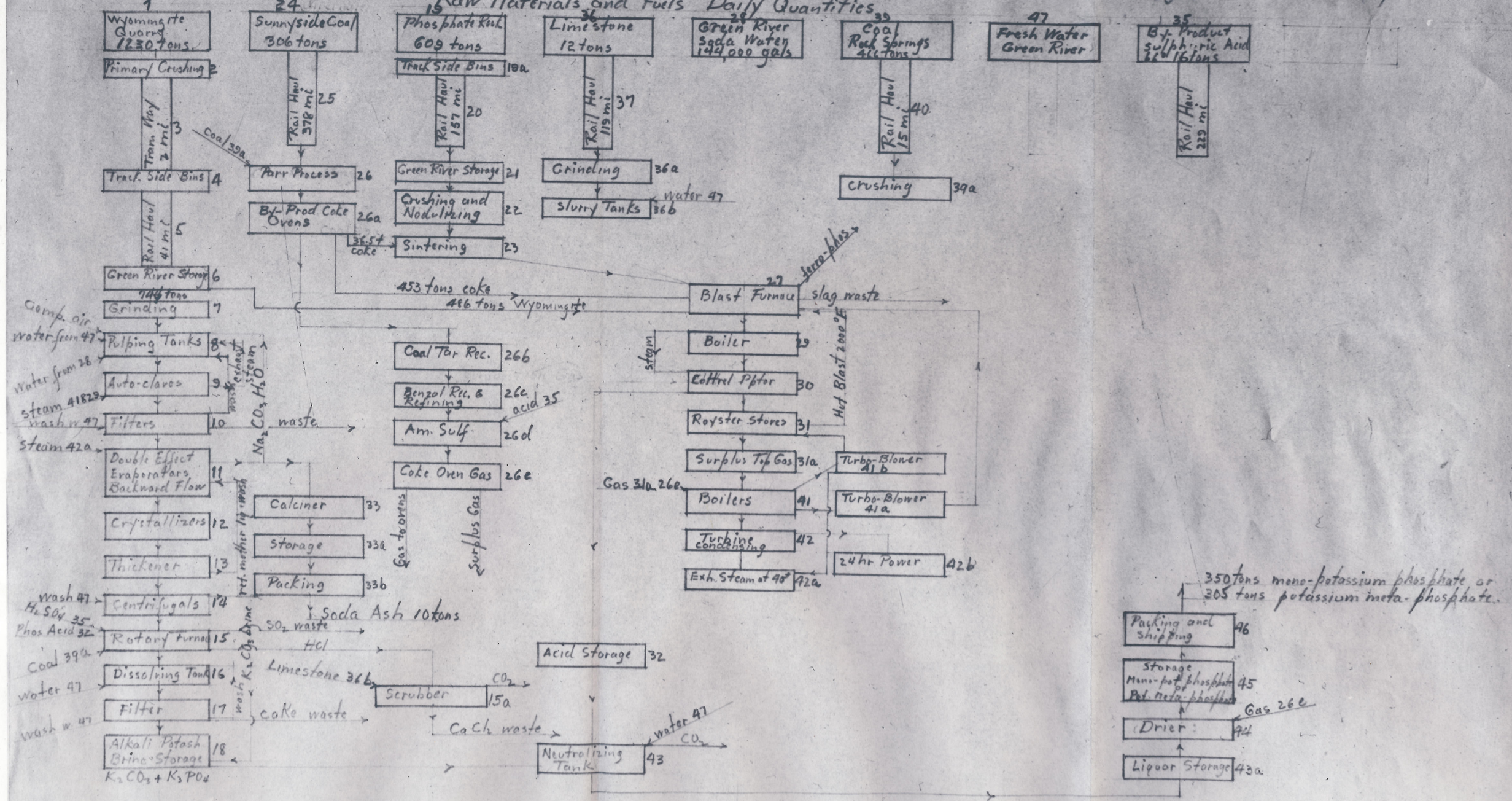
Flow Sheet No 1

Proposed Green River, Wyoming Fertilizer Industry

Product, Monopotassium Phosphate or Potassium Meta-phosphate

Unit Plant Output Daily 175 tons P_2O_5, 105 tons K_2O, 8 By-Products

Tentative Flow Sheet November 1937 Robt. D Pike Chemical Engineer Piedmont California



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Flow Sheet No 2

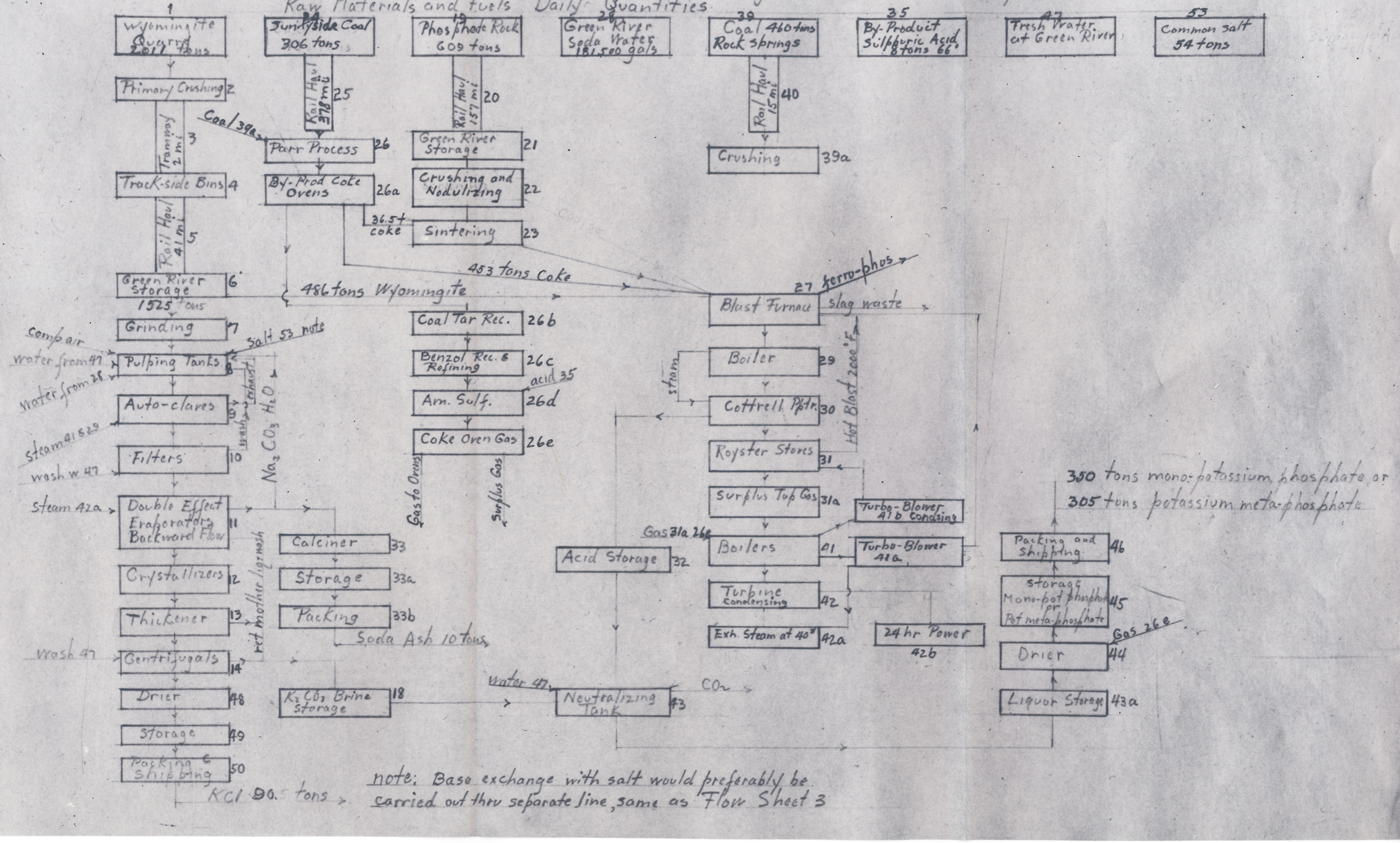
Proposed Green River Wyoming Fertilizer Industry

Product, Mono-potassium phosphate, or Potassium Meta-phosphate and Potassium Chloride

Unit Plant Output Daily 175 tons P_2O_5 with 105 tons K_2O and 56 tons K_2O as the Chloride, & By-Products

Tentative Flow Sheet November 1937. Robt. D. Pike, Chemical Engineer Piedmont, California.

Raw Materials and Fuels Daily Quantities



note: Base exchange with salt would preferably be carried out thru separate line, same as Flow Sheet 3

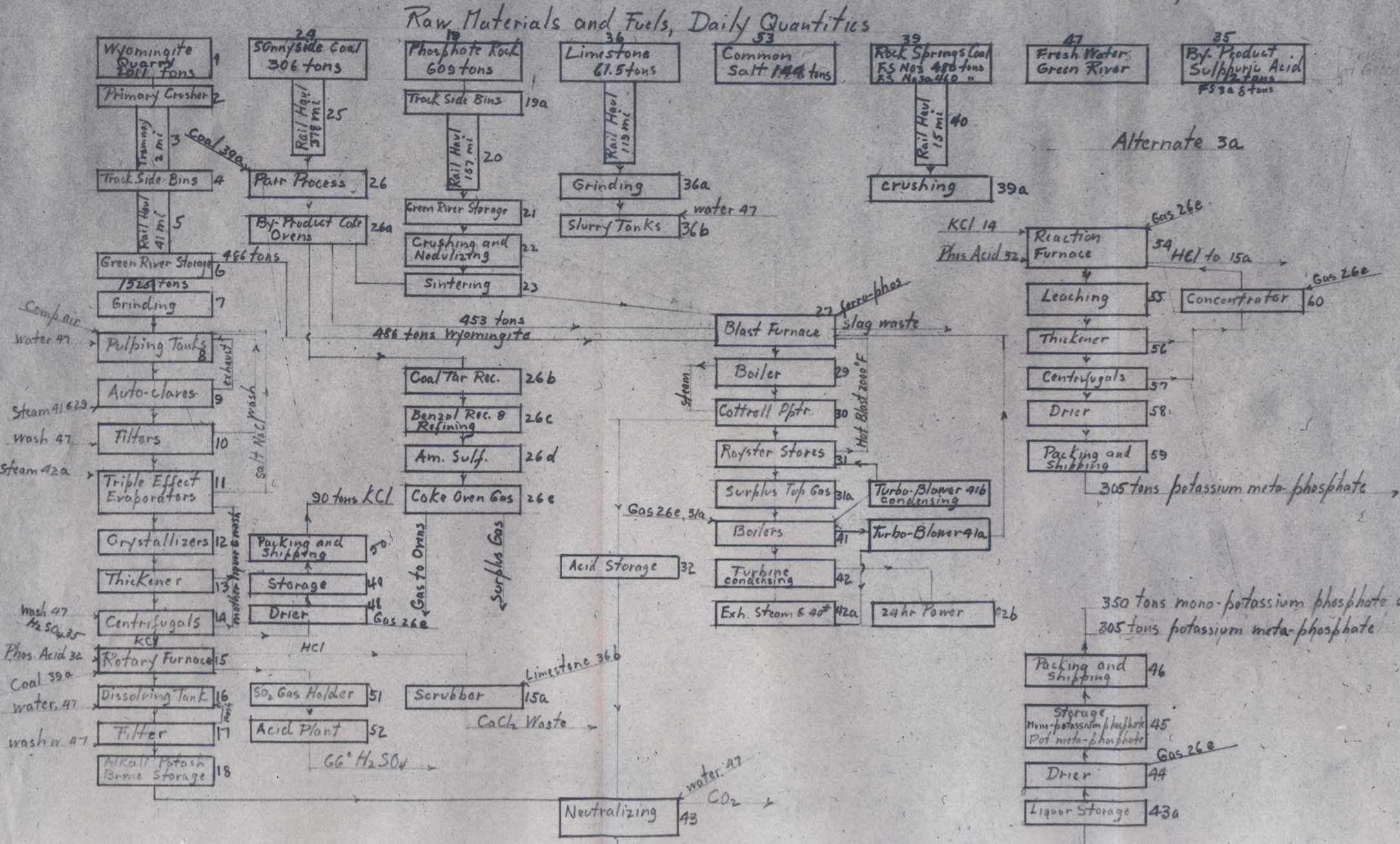
Flow Sheet No 3

Proposed Green River, Wyoming, Fertilizer Industry

Product, Mono-potassium Phosphate or Potassium Meta-Phosphate

Unit Plant Output Daily, 175 tons P_2O_5, with 105 tons K_2O and 56 tons K_2O as KCl and By-Products

Tentative Flow Sheet November 1937 Robt. D. Pike, Chemical Engineer, Piedmont, California



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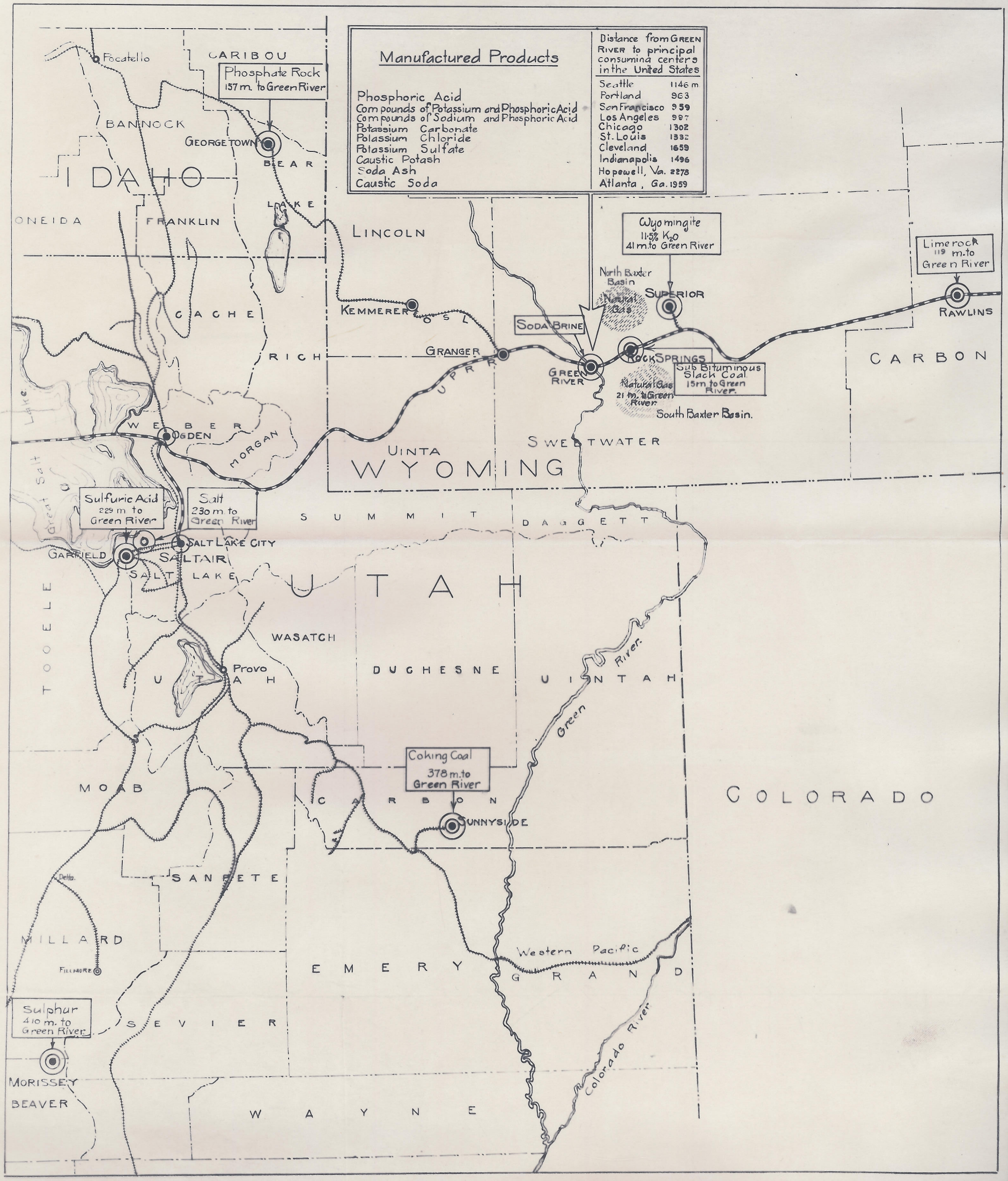
THE PROPOSED GREEN RIVER ENTERPRISE

SCALE
15 MILES = 1 INCH

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