ORNL-4296
UC-80 – Reactor Technology

GENERALIZED CAPITAL AND OPERATING COSTS FOR POWER-INTENSIVE AND ALLIED INDUSTRIES

H. E. Goeller
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OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
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Generalized Capital and Operating Costs for Power-Intensive and Allied Industries

ABSTRACT

The intent of this report is to supplement Chap. 5 of ORNL-4290, *Nuclear Energy Centers: Industrial and Agro-Industrial Complexes*, by providing the interested reader with sufficient information to duplicate the computed cost results given in Chap. 5 and to make additional independent cost studies on the 17 chemical and metallurgical products considered. The report includes (1) all of the equations and constants used in determining the various building block manufacturing cost components, (2) a brief description of the computer subroutines, including typical output data sheets, and (3) a set of tables for easily and quickly obtaining component costs at all of the reference values of all parameters used in the studies. A number of worked examples are given at the end of the report to illustrate use of these data, first for industrial building block cost determinations and then for both United States and non-United States industrial complexes.

1. INDUSTRIAL BUILDING BLOCK COST EQUATIONS AND CONSTANTS

This section contains all the equations and constants used in determining capital and operating costs, under United States economic conditions prevailing in mid-1967, for the various products studied. Equations for plant capital costs and manpower requirements at the plant reference capacities are also included. Operating costs were broken down into direct and indirect costs. The direct costs include raw materials, utilities, labor and overhead, and supplies and maintenance materials; indirect costs include depreciation based on use of the sinking fund, debt service at various costs of money, and interest on working capital.

Plant Investment Costs

Estimates of battery limits plant investment costs for all the chemical plants considered were obtained or developed for at least two capacities in order to determine appropriate exponential scaling factors. Cost-scaling equations (see Table 1) were then derived as a function of plant capacity for the range of interest for each product.

Offsites. – It should be emphasized that all investment equations are based on estimates of battery limits facilities only; to obtain total plant costs, the investment in offsite facilities must be added. Facilities which would come under the category of offsites might include:

1. offices, laboratories, and change houses;
2. a substation for supplying high-voltage electricity to the plant;
3. a water system, including a water-treatment plant, and a fire-protection system;
4. a communications system;
5. plant mobile equipment including such items as cranes, bulldozers, trucks, and a yard switch engine;
6. site preparation costs;
7. effluent ponds.

Product storage is not included in offsites but is incorporated in the battery limits estimates. In general, offsite costs would be related to the type of process being considered. For purposes of convenience, however, a series of data points were collected for various types of plants, with investments ranging from $1 million to $96 million and

Table 1. Battery Limits Plant Investment Equations

N = plant capacity in tons of indicated product per day, unless otherwise noted
D = current density, amp/ft^2
Q = dollars per square foot of active electrode surface (1 ft^2 of cathode surface plus 1 ft^2 of anode surface is equivalent to 1 ft^2 of active electrode surface)
(E) = electrolytic hydrogen
(R) = reformed hydrogen
(EF) = electric furnace phosphorus
(WA) = wet acid process phosphoric acid
L = land cost in dollars per acre for solar saltworks
P = production of solar salt (tons per acre per year) computed as

$$P = e^{0.46C}(3.68T + 15.78) ,$$

where
C = concentration factor, $1 \leqq C \leqq 3$,
T = age of salt pond in years, $0 \leqq T \leqq 10$

Product	Capital Cost, C (millions of dollars)[a]	Limiting Conditions
H_2		
(E) Allis-Chalmers[b]	$C = 7.43(400/D)^{0.29}(N/54)^{0.92}$	
(E) General Electric	$C = NQ/D + 2.96(N/54)^{0.93}$	
N_2 (E)	$C = 1.205(N/250)^{0.67}$	
NH_3		
(E) Allis-Chalmers	$C = 2.635(N/300)^{0.75}$	
(E) General Electric or De Nora	$C = 4.408(N/300)^{0.62}$	
$H_2 + NH_3$ (E)	Sum of appropriate equations above	
NH_3 (R)	$C = 7.9(N/300)^{0.71}$	
HNO_3 (for ammonium nitrate)		
(E)	$C = 3.25(N/500)^{0.66}$	
(R)	$C = 3.00(N/500)^{0.66}$	
NH_4NO_3	$C = 2.2(N/500)^{0.68}$	
Urea		
(E)	$C = 4.49(N/300)^{0.65}$	
(R)	$C = 4.11(N/300)^{0.65}$	
Nitric phosphate	$C = 5.35(N/900)^{0.70}$	N = tons/day analyzing 27-14-0
Phosphorus, P_4 (EF)[c]	$C = 0.866\ N^{0.542}$	$77 < N < 294$[d]
	$C = 18.8(N/294)^{0.84}$	$294 < N$
	$C = 1.037\ N^{0.542}$	$77 < N < 294$[e]
	$C = 22.6(N/294)^{0.9}$	$294 < N$
P_4 to H_3PO_4 conversion	$C = 1.0(N/80)^{0.80}$	N = tons/day of P_4
H_2SO_4	$C = 1.0(N/390)^{0.89}$	N = tons/day of H_2SO_4
H_3PO_4 (WA)	$C = 2.71(N/276)^{0.66}$	N = tons/day of P_2O_5
Al_2O_3 refining[f]	$C = 17(N/137)^{0.84}$	N = tons/day of Al
Al smelting	$C = 36.5(N/137)^{0.81}$	

Table 1 (continued)

Product	Capital Cost, C (millions of dollars)[a]	Limiting Conditions
Al fabrication[g]	$C = 40.2(N/137)^{0.46}$	$137 \leqq N \leqq 274$
	$C = 55.4(N/274)^{0.75}$	$274 \leqq N \leqq 685$
Solar salt (NaCl)	$C = NL/P + 7.15\ N^{0.32}$	N = millions of tons of salt per year
Chlorine[h]	$C = 6.8(N/300)^{0.83}$	
Chlorine–caustic soda[h]	$C = 9.1(N/300)^{0.82}$	N is chlorine production

[a]All cost equations are based on erected cost of battery limits facilities without offsites. All equations are assumed to have unspecified allowances for engineering, construction, and contingencies. For cases where these allowances are quantified, the amounts included are listed as a footnote.

[b]Includes a 20% allowance based on direct investment for engineering and contingencies.

[c]Includes engineering allowances ranging from $10\frac{1}{2}$ to 14% and contingency allowance of 5%, all based on direct investment.

[d]Nodulizing feed preparation system.

[e]Pelletizing feed preparation system.

[f]Includes allowances based on direct investment of 10% for contractor fees, 10% for contingencies, and 5% for engineering.

[g]Assumes 72% of aluminum is fabricated into sheet and plate and 28% into redraw rod.

[h]Includes allowances of 22% for engineering overhead and 12.2% for contingencies based on direct investment.

encompassing fertilizer, metals, chlorine, and organic chemicals production. An equation obtained by fitting 39 data points by the method of least squares is

$$\text{FROFFS} = 0.931(\text{BLC})^{-0.391}, \qquad (1)$$

where BLC is battery limits plant cost in millions of dollars and FROFFS is the fraction of battery limits investment which must be added to obtain total plant investment.[1] The equation is different from that reported in the nuclear energy center study[2] in that the allocation for offsites is increased for plant costs under $100 million, while it is about the same for complexes which might be in the $100 to $1500 million investment range.

Electrolytic Hydrogen. – For electrolytic hydrogen plants, the extra term in Table 1 (involving D) in the cost-scaling equations represents the change in investment due to changes in current density. The costs for these plants are somewhat speculative, since they represent new technology which has not been built at the present time.

[1]John M. Holmes, ORNL, personal communication (December 1968).

[2]*Nuclear Energy Centers: Industrial and Agro-Industrial Complexes*, ORNL-4290, p. 82 (November 1968).

Elemental Phosphorus. – The capital cost equations listed for elemental phosphorus production by the electric furnace process require some explanation. The first equation is representative of the battery limits costs of plants producing 77 to 294 tons/day of elemental phosphorus in single-furnace plants with furnace sizes ranging from 40,000 to 150,000 kva and a nodulizing feed preparation system. The second equation represents a scaleup in size by duplicate 150,000-kva furnaces with the same type of feed preparation system. The third and fourth equations represent the same size plants with a pelletizing feed preparation system. Feed preparation for large furnace operation is mandatory, to maintain an evenly distributed furnace burden and to maintain balanced operation. However, each feed preparation system must be designed for the phosphate rock to be used in that furnace. It has been stated that North African rock (from Algeria or Egypt) should require little preparation; therefore an elaborate system is not necessary.[3] Rock from other sources of supply, such as Florida or Idaho, does, however, require use of the most sophisticated type of feed preparation system for satisfactory operation in large electric furnaces (> 50 Mw).

[3]Joseph W. Venable, Gulf Design Corporation, private communication (January 1969).

Table 2. Battery Limits Plant Costs at Reference Capacities

Abbreviations are as defined in Table 1

Product	Current Density (amp/ft^2)	Capacity No. 1 (tons/day)	Cost No. 1 (millions of dollars)	Capacity No. 2 (tons/day)	Cost No. 2 (millions of dollars)	Capacity No. 3 (tons/day)	Cost No. 3 (millions of dollars)	Capacity No. 4 (tons/day)	Cost No. 4 (millions of dollars)
H_2 (E)									
Allis-Chalmers	400	54	7.4	108	14.1	180	22.5	540	61.8
	800	54	6.1	108	11.5	180	18.4	540	50.6
	1200	54	5.4	108	10.2	180	16.4	540	44.9
	1600	54	5.0	108	9.4	180	15.1	540	41.3
De Nora	300					180	19.0		
General Electric[a]	2500					180	12.6		
	3500					180	11.5		
	5000					180	10.8		
	7500					180	10.2		
H_2 (R)		54	5.1	108	8.1	180	11.5	540	24.0
N_2 (E)		250	1.2	500	1.9	833	2.7	2,500	5.7
NH_3 (E)[b]									
Allis-Chalmers		300	2.6	600	4.4	1000	6.5	3,000	14.8
De Nora and General Electric						1000	8.0		
NH_3 (R)		300	2.8	600	4.8	1000	7.0	3,000	16.7
HNO_3 for NH_4NO_3									
(E)		320	2.4	640	3.8	1067	5.4	3,200	11.1
(R)		320	2.2	640	3.5	1067	5.0	3,200	10.2
NH_4NO_3 (E or R)		400	1.9	800	3.0	1333	4.3	4,000	9.0
Urea									
(E)		300	4.5	600	7.1	1000	9.9	3,000	20.3
(R)		300	4.1	600	6.5	1000	9.0	3,000	18.5
HNO_3 for nitric phosphate									
(E)		248	2.0	490	3.1	827	4.2	2,480	8.1
(R)		248	1.9	490	2.8	827	3.8	2,480	7.4
Nitric phosphate (E or R)		450	3.3	900	5.4	1500	7.7	4,500	16.6

Table 2 (continued)

Product	Current Density (amp/ft^2)	Capacity No. 1 (tons/day)	Cost No. 1 (millions of dollars)	Capacity No. 2 (tons/day)	Cost No. 2 (millions of dollars)	Capacity No. 3 (tons/day)	Cost No. 3 (millions of dollars)	Capacity No. 4 (tons/day)	Cost No. 4 (millions of dollars)
Phosphorus, P_4 (EF)[c]		131	14.6	262	21.2	655	46.5	1,500	98.0
P_4 to H_3PO_4 conversion		131	1.5	262	2.6	655	5.4	1,500	10.4
H_2SO_4[d]		900	2.1	1800	3.9	4500	8.8	10,300	18.4
H_3PO_4 (WA)[e]		300	3.6	600	5.6	1500	10.3	3,435	17.8
Al_2O_3 refining[f]				137	17.0	274	30.4	685	65.7
Al smelting				137	36.5	274	64.0	685	134.4
Al fabrication				137	40.2	274	55.3	685	110.1
Solar salt[g]		3000	8.3	6000	11.3	9000	13.7	15,000	17.8
Brine electrolysis (Cl_2)		300	6.8	500	10.4	1000	18.5	2,000	32.9
NaOH evaporation		339	2.3	565	3.4	1130	5.8	2,260	9.9

[a]For cell module cost of \$50.00 per square foot; costs at \$25.00 and \$100.00 per square foot are as follows (capacity, 180 tons/day of H_2 = ≈ 1000 tons/day of NH_3):

Module Cost ($dollars/ft^2$)	Plant Cost (millions of dollars) for Current Density of –			
	$2500\ amp/ft^2$	$3500\ amp/ft^2$	$5000\ amp/ft^2$	$7500\ amp/ft^2$
25	10.8	10.3	9.9	9.6
100	16.2	14.1	12.6	11.4

[b]Cost for ammonia plant only in a hydrogen-ammonia system.

[c]Assuming pelletized feed preparation system.

[d]Capacity as tons/day of H_2SO_4 (100%).

[e]Capacity as tons/day of P_2O_5.

[f]Capacity as tons/day of Al.

[g]Assuming land cost is \$50.00 per acre, three-year aging period for ponds, and 332 production days per year.

The extrapolation of furnace design to 150 Mw is beyond the scope of present-day technology. The largest furnaces currently in operation are designed for operation at 60 Mw but are able to go to 70 Mw (about 140 tons per day of elemental phosphorus) using somewhat higher current densities. Some definite technological problems must be surmounted before a 150 Mw furnace can be built. The cover for an electric furnace is a slightly arched single span with about 20 penetrations. The limit of current casting technology is a single span of about 50 ft diameter, which is the size being used for 70-Mw furnaces. A cover with a larger diameter (perhaps 75 ft) would be required to build the larger furnace. Electrode size is another problem which must be resolved. Currently the largest furnaces are operating with 55-in.-diam prebaked electrodes, with some possibility of going to 60 in. A 150-Mw furnace would probably require development of an 84-in. electrode.

Solar Salt. – Production from a new solar salt pond will vary with time over about the first ten years of operation if a pond sealing process is not performed. The first term in the cost scaling equation (Table 1) for this process relates this variable to the amount of land required for a given production rate, assuming a certain aging period. The second term in this investment equation scales the equipment cost as a function of capacity.

All other equations are straightforward. Total plant costs (including allowances for offsites) at several reference capacities are listed in Table 2. Note that if several plants are built on the same site (complexed), the offsite allowance will be reduced because of joint use of these facilities. In this case the battery limits plant investments are summed, and Eq. (1) is used to calculate the total offsite allowance for the complex.

Raw Material Costs

Four types of raw material costs were employed in the study: (1) basic raw materials with zero cost, (2) basic raw materials with variable costs, (3) basic raw materials with fixed costs, and (4) derived raw materials with variable costs.

The first type included air, water, carbon dioxide, and evaporator brine effluent. Air used in the air liquefaction plant is free, and distilled water from a seawater evaporator (10 to 20¢ per 1000 gal) used in the electrolytic hydrogen plant is so cheap, compared with other costs, that it can be safely neglected. Carbon dioxide for urea production can be obtained by purification of the off-gases from the aluminum smelting process or from other sources and was arbitrarily assigned a zero cost (purification equipment was included in the capital cost). Brine effluent from the desalination plant was also given a zero cost, since it would merely be returned to the sea in the absence of a solar evaporation plant.

In the calculations for basic raw materials with variable costs, each variable cost took on a number of values ranging from a minimum cost in a primary natural resource area to an upper value representative of costs in an undeveloped nation far from any source. Included in this group are naphtha, phosphate rock, sulfur, bauxite, alumina, and salt. The requirements, in tons of raw material per ton of product, and the assumed unit costs in dollars per ton of each raw material are shown in Table 3. The phosphate rock requirements for the production of nitric phosphate and of phosphoric acid (by either the electric furnace or the wet acid process) are those associated with the use of higher grade Florida rock; however, the computer code was written to accommodate varying rock assays. In the aluminum production cost code, this feature was not included; therefore the bauxite requirement was fixed (2.2 tons of bauxite per ton of alumina). The salt requirement for caustic-chlorine production by brine electrolysis is theoretically a constant (1.85 tons per ton of chlorine) but is shown as a variable because of special seawater treatment requirements.[4]

A number of other basic raw materials were permitted to have only a single constant unit cost. These materials, along with their products, requirements, and unit costs, are listed in Table 4. As with phosphate rock, the requirements for matrix and coke for the phosphorus electric furnace are given for the use of high-grade Florida rock; however, other assays can be taken by the computer subroutine.

The final group of raw materials includes those derived as products from one process and used as a raw material in a second process. Included in this group are hydrogen from the electrolysis of

[4]*Nuclear Energy Centers: Industrial and Agro-Industrial Complexes*, ORNL-4290, chap. 5 (November 1968).

Table 3. Requirements and Costs of Basic Raw Materials with Variable Costs

Raw Material	Product	Requirement (tons per ton of product)	Unit Costs (dollars per ton of raw material)
Naphtha	NH_3	0.8	15, 22, 27, 35
Phosphate rock	Nitric phosphate	0.448	5, 50, 9.60, 17, 24
	P_4 and H_3PO_4 (as P_2O_5)	3.82[a]	
Sulfur	H_2SO_4 (as P_2O_5)	0.333	32, 50, 65, 80
Bauxite	Al_2O_3	2.2	3, 8, 11, 14
Al_2O_3	Al	1.93	60, 77
NaCl	Cl_2-NaOH	1.85[b]	1, 3, 6, 10

[a]For high-grade Florida rock.

[b]For complete conversion of spent cell liquor to 50% NaOH.

Table 4. Requirements and Costs of Basic Raw Materials with Constant Costs

Raw Material	Product	Requirement (tons per ton of product)	Cost (dollars per ton of raw material)
Silica matrix	Phosphorus (as P_2O_5)	1.121[a]	1
Coke	Phosphorus (as P_2O_5)	0.6[a]	17
Electrodes	Phosphorus (as P_2O_5)	13 lb/ton	14¢/lb
NaOH	Alumina	0.071 (Al)	37
$Ca(OH)_2$	Alumina	0.03	20
AlF_3	Aluminum	0.031	230
Cryolite	Aluminum	0.013	220
Fluorspar	Aluminum	0.005	35
Na_2CO_3	Aluminum	0.0009	40
Petroleum coke	Aluminum	0.41	40
Pitch	Aluminum	0.10	81
Pot materials	Aluminum		6.98[b]

[a]For high-grade Florida rock with the analyses (% dry basis): P_2O_5, 31.1; CaO, 46.5; Al_2O_3, 1.0; Fe_2O_3, 1.7; SiO_2, 9.5; F, 3.7.

[b]Per ton of aluminum.

Table 5. Requirements for Manufactured Raw Materials with Variable Costs

Raw Material	Product	Requirement (tons per ton of product)
H_2	NH_3	0.18
N_2	NH_3	0.83
NH_3	HNO_3	0.29
	NH_4NO_3	0.22
	Urea	0.58
	Nitric phosphate	0.188
HNO_3	NH_4NO_3	0.80
	Nitric phosphate	0.549
H_2SO_4	H_3PO_4	1.0
Al_2O_3	Al smelting	1.93
Al (molten)	Al fabrication	1.015
NaCl	Cl_2	1.85–3.65
NaOH-NaCl	50% NaOH	0.885[a]
Cl_2	HCl	0.97

[a]Tons per ton of chlorine.

water and steam-naphtha reforming and nitrogen from air liquefaction, both for use in ammonia synthesis; ammonia for use in nitric acid, ammonium nitrate, urea, and nitric phosphate production; and nitric acid for use in ammonium nitrate and nitric phosphate manufacture. In the naphtha reforming case and with nitric acid production the air liquefaction plant can be eliminated since the nitrogen can be obtained from the reformer off-gases and the nitric acid plant tail gases respectively. Alumina produced from bauxite is the input for aluminum production, and salt from a solar salt works is the raw material for caustic-chlorine production by brine electrolysis. All these materials have unit costs which are determined by the cost of their production in the initial process. Table 5 presents a list of these raw materials along with their requirements and products.

Utilities Costs

The second basic direct manufacturing cost determined for each product was the cost of utilities. The utilities required to produce the products studied included electricity, water, steam, and fossil fuel. Both cooling water and distilled water (listed in the various computer codes as process water, boiler feedwater, or condensate) and prime and exhaust steam were required. Fossil fuel (natural gas or fuel oil) was needed for alumina and aluminum production.

The requirements and unit costs for each of the utilities used in the manufacture of each product are listed in Table 6. In all calculations the manufacturing costs for all products were computed for electric power costs of 1, 2, 4, and 8 mills/kwhr, since power cost was one of the major variables used in the study. Since distilled water and steam costs would be closely related to power cost in a nuclear-reactor–seawater-evaporator system, the computer code was designed to include, also, variable water and steam costs. Distilled water costs of 7, 12, 30, and 50¢ per 1000 gal, prime steam costs of 6, 15, 30, and 50¢/MMBtu, and exhaust steam costs of 2, 6, 15, and 25¢/MMBtu were used. Cooling water costs of 2¢ per 1000 gal and fuel costs of 50¢/MMBtu were used in nearly all cases. The electricity requirement for electric furnace phosphorus is that required for high-grade Florida phosphate rock (Table 3).

Manpower Requirements and Labor and Overhead Costs

The direct operating manpower requirements for all the processes studied were determined as a function of plant capacity, and equations were written for all the capacity ranges studied. In most cases the derived equations were of exponential form. However, in the production of nitrogen by air liquefaction, one operator per shift was used regardless of plant capacity; in the evaporation of caustic-chlorine cell liquor to produce 50% NaOH, two operators per shift were required at capacities below 1130 tons/day of NaOH and four operators per shift above this capacity. The derived equations for all products are given in Table 7. As indicated in the table, the equations for electric furnace production of P_4 and its conversion to H_3PO_4 are algebraic and continuous, but the equations for the production of H_2SO_4 and H_3PO_4 by the wet acid process are stepped functions, being discontinuous at 600 and 1200 tons of P_2O_5 per day. It should be noted that the maintenance labor for

Table 6. Utility Requirements and Unit Costs

Electricity at 1, 2, 4, and 8 mills/kwhr

Product	Electricity (kwhr per ton of product)	Cooling Water		Distilled Water		Prime Steam		Exhaust Steam		Fossil Fuel	
		(gal/ton)	(¢ per 1000 gal)	(gal/ton)	(¢ per 1000 gal)	(MMBtu/ton)	(¢/MMBtu)	(MMBtu/ton)	(¢/MMBtu)	(MMBtu/ton)	(¢/MMBtu)
		$\times 10^3$		$\times 10^3$							
H_2											
(E)	*a*	*b*	0.5	0.39	c						
(R)		22.5	2	0.6	16						
				0.235	c						
N_2 (E)	0.181	4.4	2								
NH_3											
(E)	525	18.5	2	0.32	16						
(R)	650	18.5	2								
HNO_3											
(E)	5	23	0.5	0.34	16						
(R)	5	23	2	0.34	16						
NH_4NO_3	35	1.2	2								
Urea	136	19.9	2			2.4	*d*				
Nitric phosphate	14	1.96	2			2.2	*d*				
P_4 (EF)	Variable	11	2					1.9	*e*		
P_4 to H_3PO_4	40	20	2								
H_2SO_4 (WA)	8	22	2	1.0	16						
H_3PO_4 (WA)	300	5.0	2								
Al_2O_3	200			0.84	c	6.0	*d*			10	50
Al smelting	13,000					1.61	*d*			1.95	50
Al fabrication	1,200			12	c					10	50
Salt (NaCl)	4										
Cl_2 (–NaOH)	3,200	15	2					1.0	*e*		
50% NaOH	100	10	2					6.5	*e*		

[a]Number of kilowatt-hours per ton of NH_3 varies with current density in Allis-Chalmers cells as follows: at 400, 800, 1200, and 1600 amp/ft^2, kwhr/ton = 7430, 7760, 8240, and 8770 respectively.

[b]Gallons per ton of NH_3 = 7500, 11,100, 15,900, and 17,600 for above current densities respectively.

[c]7, 12, 30, and 50¢/1000 gal.

[d]6, 15, 30, and 50¢/MMBtu.

[e]2, 6, 15, and 25¢/MMBtu.

Table 7. Manpower vs Capacity Equations for All Products

Product	Manpower Equation, M = Number of Operators per Shift	Remarks
H_2	$M = e^{0.000462N}$	N = tons of NH_3 per day
N_2	$M = 1$	N = tons of NH_3 per day
NH_3	$M = 0.318\ N^{0.25}$	
HNO_3	$M = (N/500)^{0.65}$	
NH_4NO_3	$M = 15\ (N/625)^{0.83}$	
	$M_m = 2.57\ (N/625)^{0.70}$	Maintenance
Urea	$M = 10\ (N/300)^{0.69}$	
Nitric phosphate	$M = 16\ (N/432)^{0.67}$	
P_4 (EF)	$M = 25 + 3\ [(N/687) - 1]$	
P_4 to H_3PO_4	$M = N/300$	N = tons of P_2O_5 per day
H_2SO_4	$M = 4,\ N < 600$	N = tons of P_2O_5 per day
	$M = 5,\ 600 < N < 1200$	N = tons of P_2O_5 per day
	$M = 6,\ 1200 < N$	N = tons of P_2O_5 per day
H_3PO_4 (WA)	$M = 21,\ N < 630$	N = tons of P_2O_5 per day
	$M = 25,\ 630 < N < 1230$	N = tons of P_2O_5 per day
	$M = 21 + 4\ [(N/1200) - 1],\ 1230 < N$	N = tons of P_2O_5 per day
Al_2O_3 refining	$M = 0.149\ N^{0.70}$	
Al smelting	$M = 0.95\ N^{0.75}$	
Al fabrication	$M = 2.82\ N^{0.72}$	
Salt (NaCl)	$M = 100\ (N/3000)^{0.69}$	
Cl_2 (–NaOH)	$M = 3\ (N/300)^{0.58}$	
	$M_m = 4\ (N/300)^{0.81}$	Maintenance
	$M_s = 1\ (N/300)^{0.50}$	Supervision
50% NaOH	$M = 2,\ N \leqq 1130$	
	$M = 4,\ N > 1130$	

Table 8. Total Manpower Requirements at Reference Capacities for All Products

C = capacity (tons of product per day)

M = total operating personnel, men per shift; for total manpower requirements assume four shifts

	I		II		III		IV	
	C	M	C	M	C	M	C	M
Hydrogen	54	3	108	3	180	3	540	9
Nitrogen	250	1	500	1	833	1	2500	1
Ammonia (including H_2)	300	8	600	8	1,000	8	3000	20
Nitric acid	320	3	640	3	1,067	3	3200	9
Ammonium nitrate	400	11	800	22	1,333	33	4000	81
Urea	300	12	600	22	1,000	30	3000	66
Nitric phosphate	450	36	900	51	1,500	68	4500	118
Phosphorus (EF)[a]	300	37	600	37	1,500	52	3435	77
P_4 to H_3PO_4 conversion[a]	300	1	600	2	1,500	5	3435	12
Sulfuric acid	900	4	1800	4	4,500	6		
Phosphoric acid[a] (WA)	300	34	600	42	1,500	63	3435	96
Alumina[b]	274	8	548	13	1,370	27		
Aluminum smelting	137	60	274	103	685	205		
Aluminum fabrication	137	96	274	157	685	304		
Solar salt	3000	100	9000	220	15,000	300		
Chlorine	300	8	500	11	1,000	17	2000	29
Chlorine-caustic soda[c]	300	10	500	13	1,000	19	2000	33

[a]Capacity is tons/day of P_2O_5.

[b]Capacity is tons/day of Al_2O_3.

[c]Capacity given is tons/day of Cl_2; for NaOH production, 1 ton of Cl_2 is equivalent to 1.13 tons of caustic soda.

NH_4NO_3 production and both maintenance and supervisory labor for chlorine-caustic production are also given in exponential equation form. Typical total manpower requirements for all products at their four reference capacities are shown in Table 8. All manpower equations were handled as fixed point numbers, and these were rounded down to the nearest whole number.

Other Materials Costs

The last of the direct costs which were evaluated is for other materials, which include operating materials and supplies (other than raw materials), maintenance supplies, and catalysts and chemicals. The method of obtaining these costs, which are usually small, is shown in Table 9. Costs of operating supplies are generally obtained as a fraction of labor cost, but in two cases (electrolytic hydrogen and solar salt) they were determined as a fraction of plant investment. In several other cases they are a constant cost. The major part of the operating supply costs for NH_4NO_3, urea, and nitric phosphate production is plastic bags for bagging the products; in each case 21 bags at 30¢ apiece are required per ton of product. Maintenance material costs are in all cases determined as a fraction of plant capital investment; this fraction varies from 2 to 10% for the various products. Catalyst and chemical costs are constants in all cases except for wet-process phosphoric acid, where costs

Table 9. Other Materials Costs for Production of All Products

L = total labor costs

$$F = \text{capital cost factor} = \frac{\text{plant cost}}{(365\ \text{days/year})\ (\text{plant efficiency})\ (\text{tons of product per day})}$$

Product	Cost (dollars per ton of product)		
	Operating Supplies	Maintenance Materials	Catalysts and Chemicals
H_2			
(E)	$0.002F$	$0.02F$	
(R)	$0.05L$	$0.02F$	0.75
N_2 (E)	0.20		
NH_3			
(E)	$0.05L$	$0.02F$	0.25
(R)	$0.05L$	$0.02F$	1.00
HNO_3	$0.05L$	$0.02F$	0.40
NH_4NO_3	$0.05L_1 + 6.30$	$0.02F$	1.50
Urea	6.65	$0.03F$	1.00
Nitric phosphate	6.80	$0.04F$	1.10
P_4 (EF)	$0.05L$	$0.04F$	0.83
P_4 to H_3PO_4		$0.10F$	
H_2SO_4			
H_3PO_4 (WA)		$0.06F$	$0.05F$
Al_2O_3	0.60	$0.02F$	0.10
Al smelting		$0.02F$	
Al fabrication		$0.031F$	0.75
Salt (NaCl)	$0.05F$	$0.05F$	
Cl_2 (−NaOH)	0.70	$0.022F$	3.70
50% NaOH		$0.02F$	
HCl		$0.02F$	

are given as a fraction of total plant cost. Of the $3.70 catalyst and chemical cost for the caustic-chlorine plant, 92% is for electrolytic cell renewal materials.

The sum of all the previous costs is the total direct operating cost.

Indirect Costs

The indirect cost factor used in the energy center study, Eq. (2), reflects allowances for depreciation, debt service, and interest during construction. Depreciation and debt service were calculated by means of the capital recovery factor, crf:

$$\text{crf} = \frac{i(1+i)^n}{(1+i)^n - 1}, \tag{2}$$

where i is interest rate or cost of borrowed money and n is investment lifetime in years. Industrial plants were assumed to have a uniform lifetime of 15 years. This is conservative for a process such as aluminum but may be optimistic for a process such as electrolytic hydrogen. Four values of the cost of money were evaluated: 2.5, 5, 10, and 20%. Tabular data on capital-dependent indirect costs are reported as dollars per ton of product and are obtained by

$$\text{dollars/ton} = \text{crf } C/365EN \ , \tag{3}$$

where

365 = number of days per year,

C = battery limits plant investment,

E = plant on-stream efficiency as a decimal fraction,

N = plant capacity in tons of product per day.

To obtain the interest on working capital the four operating costs and the interest-dependent indirect costs (in dollars per ton) are added together to give the sum S, which is then used in the equation

$$\text{interest on working capital} = \frac{S}{(365E/60i) - 1} . \tag{4}$$

The values of E for the different processes studied are given below. Finally, gross manufacturing costs were computed as the sum of all direct and indirect costs by adding interest on working capital to the prior sum S.

On-Stream Efficiency and Plant Reliability

In general, few industrial plants operate either continuously or at full capacity at all times. In order to take this into account, an on-stream efficiency factor based on experience in the various chemical and metallurgical industries was used. The on-stream efficiency factor employed for ammonia and ammonia-derived fertilizer manufacture and for caustic-chlorine production was 0.95. For production of phosphoric acid, both by the wet acid process and from electric furnace phosphorus, a factor of 0.93 was used. The factor for the solar saltworks was 0.91. The aluminum production facility was assumed to have an on-stream efficiency factor of 1.00.

2. COMPUTER CODE DESCRIPTION

This section includes a brief description of the computer-code subroutines used to generate building block and industrial complex costs and includes typical output sheets for all the subroutines employed.

All programs were written in FORTRAN 63 for use with a CDC 1604 computer.[5] Four groups of subroutines were written for determining capital and manufacturing costs of (1) H_2, N_2, NH_3, HNO_3, NH_4NO_3, urea, and nitric phosphate; (2) H_2SO_4, H_3PO_4, P_4, and conversion of P_4 to H_3PO_4; (3) Al_2O_3, aluminum smelting, and aluminum fabrication; and (4) salt (NaCl), NaOH-Cl_2, 50% NaOH, and HCl. Each of the subroutines was under the control of the calling program AISP1, which guided the computations. Subroutines INPUT and CHECK read in and printed out the input and output data respectively.

The four subroutines CALCI, PHOSCC, CALCALC, and CALCLC compute the battery limits plant capital investments at any capacity for each of the product groups listed above respectively; printout is achieved through subroutines OUT1, OUTPCC, OUTALC, and OUTCLC respectively. Subroutine CALCI also permits an evaluation of capital cost differences resulting from the use of different current densities for the Allis-Chalmers and General Electric water electrolysis cells. Subroutine PHOSOC allows the use of two capital cost vs capacity equations for low, intermediate, and high electric furnace phosphorus plant capacities respectively.

Manufacturing costs for each of the products in the four product groups were then computed. Each group will now be discussed in turn. Subroutine CALCH calculates the production cost of hydrogen both by the electrolysis of water and by steam-naphtha reforming. A unique feature of subroutine CALCH is that it permits cost evaluation for different electrolytic cell current densities in the electrolytic hydrogen case. The output from this subroutine is entered as a raw materials cost into subroutine CALCN, which computes ammonia manufacturing cost for both hydrogen sources. Subroutine CALCN also computes the production cost of nitrogen by air liquefaction for use in determining ammonia production cost for the electrolytic hydrogen case only. The output from subroutine CALCN is entered as a raw materials cost into each of the remaining subroutines, since each of them requires ammonia as an input. Subroutine CALC8 computes

[5]Has since been rewritten in FORTRAN IV for use with an IBM 360 computer.

the manufacturing cost for nitric acid, and its output is used as an input to subroutines CALC9 and CALCNP, which compute the production cost of ammonium nitrate and nitric phosphate respectively. Finally, subroutine CALCUR calculates the production cost of urea. In all the last four subroutines, calculations again include the use of hydrogen from both sources. The printout of all six of the above subroutines is done with subroutine OUT 2.

Phosphoric acid manufacturing costs are computed with subroutines PHOSOC and H2SO4. Subroutine PHOSOC computes the manufacturing cost of elemental phosphorus by the electric furnace method and phosphoric acid by the wet acid process. Subroutine H2SO4 calculates the production cost of sulfuric acid, which is entered into subroutine PHOSOC as a raw materials cost for the wet acid process, and the cost of converting elemental phosphorus to phosphoric acid, which is entered into subroutine PHOSOC at the end as an added cost. A feature of subroutine PHOSOC is that it contains, at the start of the subroutine, a material balance computation which permits different phosphate rock assays to be entered as input. Printout for subroutine PHOSOC is done with subroutine OUTPOC.

The cost of producing alumina and aluminum is computed by subroutines CALCALE, CALCALS, and CALCALF. Subroutine CALCALE calculates alumina refining (from bauxite) costs. Subroutine CALCALS calculates the costs of the electrolytic smelting of alumina to produce molten aluminum and includes also the manufacturing costs of the carbon anodes required for smelting. Alumina raw material cost can be entered into subroutine CALCALS either as a constant or as the cost as computed in subroutine CALCALE. Finally, subroutine CALCALF computes the cost of producing aluminum sheet and bar using the molten aluminum costs, calculated in subroutine CALCALS, as a raw material cost input. The printout for these three subroutines is achieved through the use of subroutine OUTALO.

Manufacturing costs for the products of the final product group – salt, Cl_2, 50% NaOH, and HCl – are calculated with subroutines CALSOLO, CALCLO, and CASHCL. Subroutine CALSOLO computes the production cost of solar salt; subroutine CALCLO, the cost of producing chlorine by brine electrolysis; and subroutine CASHCL, the costs for producing 50% caustic for sale from the cell liquor and HCl for seawater treatment by the recombination of hydrogen and chlorine from the electrolysis cells. Salt raw material cost can be entered into subroutine CALCLO either as a set of constants or as the cost determined in subroutine CALSOLO. Subroutine CALCLO can also take into account varying salt requirements determined by the ratio of Cl_2 to NaOH desired for sale, which can in turn be set by the ratio of HCl to NaOH used for seawater treatment. As noted previously, use of NaOH-NaCl cell liquor for seawater treatment results in loss of the contained salt and increases the salt requirement for the brine electrolysis plant; when 50% NaOH is produced, the contained salt precipitates and is recycled to the electrolysis cells. Printout of results for these subroutines is done by subroutine OUTCLO.

Typical output data for all the above subroutines are given in Figs. 1–17. The figures are preceded by an index to acquaint the reader with the format used in the calculations.

Computer Program for Industrial Complexing

For computer programming, a main calling routine, AISP-2, and a subroutine, COMPLEK, were written to perform all calculations necessary to combine costs of the various industrial processes into a complex using subroutines from the building block program AISP-1 and computed off-site facility costs.

The results of a typical computer run for a complex located in a developing country are shown in Figs. 18 and 19 for a cost of money of 10%. Figure 18 provides a summary of the annual tonnages and costs of major raw materials needed for the complex. The example complex, which produces ammonia, elemental phosphorus, aluminum, caustic, and chlorine, requires bauxite, phosphate rock, coke, and silica gravel as raw materials. Peak electrical load, actual total annual power, and peak prime steam requirements are also listed in the output from the computer program. These utility data are used in sizing the reactor for the heat and power requirements of the combined industries in a nuclear industrial or nuclear agro-industrial complex, as described in Chap. 7 of ORNL-4290.

Capacities, capital investments, annual operating costs at the four power costs of 1, 2, 4, and 8 mills/kwhr, indirect costs, and annual product values are tabulated in Fig. 19.

INDEX TO INDUSTRIAL BUILDING BLOCK TYPICAL OUTPUT SHEETS

Figure No.	Subroutine	Cost Type	Products
1	CALC1	Capital	H_2, N_2, NH_3, and NH_3 derivatives
2	CALCH	Manufacturing	H_2
3	CALCN	Manufacturing	NH_3 and N_2
4	CALC8	Manufacturing	HNO_3
5	CALC9	Manufacturing	NH_4NO_3
6	CALCUR	Manufacturing	Urea
7	CALCNP	Manufacturing	Nitric phosphate
8	PHOSCC	Capital	P_4 and H_3PO_4
9	PHOSOC	Manufacturing	P_4 and H_3PO_4
10	CALCALC	Capital	Al_2O_3, aluminum smelting, and aluminum fabrication
11	CALCALE	Manufacturing	Al_2O_3 refining
12	CALCALS	Manufacturing	Aluminum smelting
13	CALCALF	Manufacturing	Aluminum fabrication
14	CALCLC	Capital	NaCl, NaOH-Cl_2, 50% NaOH, HCl, and solar salt
15	CALSOLO	Manufacturing	Solar NaCl
16	CALCLO	Manufacturing	Brine electrolysis
17	CASHCL	Manufacturing	50% NaOH

CALCULATED RESULTS   ALLIS-CHALMERS CELL
NAPHTHA COST IS $27.00/TON, INCOME TAX   0   CURRENT DENSITY   800

TABLE I   CAPITAL INVESTMENTS, MILLIONS OF $ 1000 TON/DAY NH3 PLANT

			CAPACITY	PLANT INVESTMENT
NAPHTHA REFORMING				
1	HYDROGEN PLANT	MSCF/D	76000.00	11.490179
2	NH3 PLANT	TONS/D	1000.00	7.007960
3	TOTAL NH3			18.498139
ELECTROLYTIC				
4	HYDROGEN PRODUCTION	MSCF/D	66700.00	18.442331
5	NITROGEN PRODUCTION	TONS/D	840.00	2.727343
6	NH3 PLANT	TONS/D	1000.00	6.508225
7	ELECTROLYTIC NH3 TOTAL			27.677898
NH4NO3 PRODUCTION REFORMING CASE				
	TOTAL NH3		1000.00	18.498139
	HNO3 PLANT		1167.94	5.256130
	NH4NO3 PLANT		1459.92	4.539473
	TOTAL			28.293741
NH4NO3 PRODUCTION ELECTROLYTIC CASE				
	TOTAL NH3		1000.00	27.677898
	HNO3 PLANT		1167.94	5.694140
	NH4NO3 PLANT		1459.92	4.539473
	TOTAL			37.911511
UREA PRODUCTION, AMMONIA BY ELECTROLYSIS				
22	UREA PLANT		1000	9.876334
UREA PRODUCTION, AMMONIA BY NAPHTHA REFORMING				
23	UREA PLANT		1000	9.032428
NITRIC PHOSPHATE PRODUCTION REFORMING CASE				
	HNO3 PLANT		795.00	3.736302
	NITRIC PHOSPHATE PLANT		1440.00	7.444750
	TOTAL			11.181052
NITRIC PHOSPHATE PRODUCTION ELECTROLYTIC CASE				
	HNO3 PLANT		795.00	4.075966
	NITRIC PHOSPHATE PLANT		1440.00	7.444750
	TOTAL			11.520716

Fig. 1. Typical Computer Output of Capital Costs of H_2, N_2, NH_3, HNO_3, NH_4NO_3, Urea, and Nitric Phosphate Plants.

CALCULATED RESULTS ALLIS-CHALMERS CELL
NAPHTHA COST IS $27.00/TON, INCOME TAX 0 CURRENT DENSITY 800

1000 TON/DAY NH3 PLANT

TABLE 2 HYDROGEN PRODUCTION COSTS

		ELECTROLYSIS $/TON NH3				NAPHTHA REFORMING $/TON NH3			
1	RETURN ON INVESTMENT	.10	.10	.10	.10	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	1.00	2.00	4.00	8.00
	RAW MATERIALS AND UTILITIES								
4	PHOSPHATE ROCK	0	0	0	0	0	0	0	0
5	NAPHTHA OR NH3	0	0	0	0	21.60	21.60	21.60	21.60
6	ELECTRIC POWER	7.77	15.55	31.10	62.20	0	0	0	0
7	NITROGEN OR HNO3	0	0	0	0	0	0	0	0
8	COOLING WATER	.06	.06	.06	.06	.45	.45	.45	.45
9	BOILER FEEDWATER	.03	.05	.12	.19	.10	.10	.10	.10
10	CONDENSATE OR STEAM	0	0	0	0	.02	.03	.07	.12
11	SUBTOTAL	7.86	15.65	31.27	62.45	22.16	22.17	22.22	22.26
	LABOR AND SUPERVISION								
13	OPERATING LABOR	.10	.10	.10	.10	.10	.10	.10	.10
14	MAINTENANCE LABOR	.13	.13	.13	.13	.50	.50	.50	.50
15	OPERATING SUPERVISION	.06	.06	.06	.06	.06	.06	.06	.06
16	SUBTOTAL	.29	.29	.29	.29	.66	.66	.66	.66
	MATERIALS								
18	OPERATING SUPPLIES	.11	.11	.11	.11	.03	.03	.03	.03
19	MAINTENANCE MATERIALS	1.06	1.06	1.06	1.06	.66	.66	.66	.66
20	CATALYSTS AND CHEMICALS	0	0	0	0	.75	.75	.75	.75
21	SUBTOTAL	1.17	1.17	1.17	1.17	1.45	1.45	1.45	1.45
22	PLANT OVERHEAD	.18	.18	.18	.18	.40	.40	.40	.40
	INDIRECT COSTS								
24	RECOVERY OF INVESTMENT	1.67	1.67	1.67	1.67	1.04	1.04	1.04	1.04
25	RETURN ON INVESTMENT	5.32	5.32	5.32	5.32	3.31	3.31	3.31	3.31
26	INTEREST ON WORK. CAP.	.29	.43	.70	1.25	.51	.51	.51	.51
27	SUBTOTAL	7.28	7.42	7.70	8.24	4.87	4.87	4.87	4.87
28	TOTAL MANUFACTURING COST	16.78	24.71	40.60	72.33	29.53	29.54	29.58	29.63
29	OXYGEN CREDIT	0	0	0	0	0	0	0	0
30	NET MANUFACTURING COST	16.78	24.71	40.60	72.33	29.53	29.54	29.58	29.63
31	FEDERAL INCOME TAX	0	0	0	0	0	0	0	0
32	TOTAL	16.78	24.71	40.60	72.33	29.53	29.54	29.58	29.63
	NUMBER OF OPERATORS		1.00				1.00		

Fig. 2. Typical Computer Output of Hydrogen Manufacturing Costs.

CALCULATED RESULTS ALLIS-CHALMERS CELL
NAPHTHA COST IS $27.00/TON, INCOME TAX 0 CURRENT DENSITY 800

1000 TON/DAY NH3 PLANT

TABLE 3 TOTAL NH3 PRODUCTION COSTS (WITHOUT OFFSITES), $/TON NH3

		ELECTROLYSIS				NAPHTHA REFORMING			
1	RETURN ON INVESTMENT	.10	.10	.10	.10	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	1.00	2.00	4.00	8.00
	RAW MATERIALS AND UTILITIES								
4	PHOSPHATE ROCK	0	0	0	0	0	0	0	0
5	NAPHTHA OR NH3	0	0	0	0	21.60	21.60	21.60	21.60
6	ELECTRIC POWER	8.30	16.60	33.20	66.40	.65	1.30	2.60	5.20
7	NITROGEN OR HNO3	1.81	1.99	2.36	3.10	0	0	0	0
8	COOLING WATER	.43	.43	.43	.43	.82	.82	.82	.82
9	BOILER FEEDWATER	.03	.05	.12	.19	.15	.15	.15	.15
10	CONDENSATE OR STEAM	0	0	0	0	.02	.03	.07	.12
11	SUBTOTAL	10.56	19.06	36.10	70.11	23.23	23.90	25.24	27.88
	LABOR AND SUPERVISION								
13	OPERATING LABOR	.20	.20	.20	.20	.20	.20	.20	.20
14	MAINTENANCE LABOR	.39	.39	.39	.39	.76	.76	.76	.76
15	OPERATING SUPERVISION	.18	.18	.18	.18	.18	.18	.18	.18
16	SUBTOTAL	.78	.78	.78	.78	1.14	1.14	1.14	1.14
	MATERIALS								
18	OPERATING SUPPLIES	.15	.15	.15	.15	.09	.09	.09	.09
19	MAINTENANCE MATERIALS	1.44	1.44	1.44	1.44	1.07	1.07	1.07	1.07
20	CATALYSTS AND CHEMICALS	.25	.25	.25	.25	1.00	1.00	1.00	1.00
21	SUBTOTAL	1.83	1.83	1.83	1.83	2.16	2.16	2.16	2.16
22	PLANT OVERHEAD	.69	.69	.69	.69	.69	.69	.69	.69
	INDIRECT COSTS								
24	RECOVERY OF INVESTMENT	2.26	2.26	2.26	2.26	1.68	1.68	1.68	1.68
25	RETURN ON INVESTMENT	7.20	7.20	7.20	7.20	5.33	5.33	5.33	5.33
26	INTEREST ON WORK. CAP.	.41	.56	.86	1.46	.60	.61	.64	.68
27	SUBTOTAL	9.87	10.02	10.32	10.92	7.62	7.63	7.65	7.70
28	TOTAL MANUFACTURING COST	23.73	32.38	49.72	84.33	34.84	35.51	36.88	39.57
29	OXYGEN CREDIT	0	0	0	0	0	0	0	0
30	NET MANUFACTURING COST	23.73	32.38	49.72	84.33	34.84	35.51	36.88	39.57
31	FEDERAL INCOME TAX	0	0	0	0	0	0	0	0
32	TOTAL	23.73	32.38	49.72	84.33	34.84	35.51	36.88	39.57
	NUMBER OF OPERATORS		2.00				2.00		

Fig. 3. Typical Computer Output of Ammonia Manufacturing Costs.

CALCULATED RESULTS ALLIS CHALMERS CELL
NAPHTHA COST IS $27.00/TON, INCOME TAX 0 CURRENT DENSITY 800

1000 TON/DAY NH3 PLANT

TABLE 4 NITRIC ACID PRODUCTION COSTS, $/TON HNO3, FOR 1067.1 TONS/DAY HNO3

		ELECTROLYSIS				NAPHTHA REFORMING			
1	RETURN ON INVESTMENT	.10	.10	.10	.10	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	1.00	2.00	4.00	8.00
	RAW MATERIALS AND UTILITIES								
4	PHOSPHATE ROCK	0	0	0	0	0	0	0	0
5	NAPHTHA OR NH3	3.45	5.87	10.70	20.35	7.69	8.09	8.48	9.24
6	ELECTRIC POWER	.01	.01	.02	.04	.01	.01	.02	.04
7	NITROGEN OR HNO3	0	0	0	0	0	0	0	0
8	COOLING WATER	.12	.12	.12	.12	.46	.46	.46	.46
9	BOILER FEEDWATER	.34	.34	.34	.34	.05	.05	.05	.05
10	CONDENSATE OR STEAM	0	0	0	0	0	0	0	0
11	SUBTOTAL	3.91	6.33	11.18	20.85	8.41	8.61	9.01	9.80
	LABOR AND SUPERVISION								
13	OPERATING LABOR	.09	.09	.09	.09	.09	.09	.09	.09
14	MAINTENANCE LABOR	.12	.12	.12	.12	.12	.12	.12	.12
15	OPERATING SUPERVISION	.05	.05	.05	.05	.05	.05	.05	.05
16	SUBTOTAL	.26	.26	.26	.26	.26	.26	.26	.26
	MATERIALS								
18	OPERATING SUPPLIES	.01	.01	.01	.01	.01	.01	.01	.01
19	MAINTENANCE MATERIALS	.29	.29	.29	.29	.27	.27	.27	.27
20	CATALYSTS AND CHEMICALS	.40	.40	.40	.40	.40	.40	.40	.40
21	SUBTOTAL	.70	.70	.70	.70	.68	.68	.68	.68
22	PLANT OVERHEAD	.16	.16	.16	.16	.16	.16	.16	.16
	INDIRECT COSTS								
24	RECOVERY OF INVESTMENT	1.06	1.06	1.06	1.06	.91	.91	.91	.91
25	RETURN ON INVESTMENT	3.35	3.35	3.35	3.35	2.89	2.89	2.89	2.89
26	INTEREST ON WORK. CAP.	.17	.21	.29	.46	.23	.24	.24	.26
27	SUBTOTAL	4.57	4.62	4.70	4.87	4.03	4.03	4.04	4.05
28	TOTAL MANUFACTURING COST	9.61	12.07	17.00	26.84	13.54	13.74	14.15	14.95
29	OXYGEN CREDIT	0	0	0	0	0	0	0	0
30	NET MANUFACTURING COST	9.61	12.07	17.00	26.84	13.54	13.74	14.15	14.95
31	FEDERAL INCOME TAX	0	0	0	0	0	0	0	0
32	TOTAL	9.61	12.07	17.00	26.84	13.54	13.74	14.15	14.95
	NUMBER OF OPERATORS		1.00				1.00		

Fig. 4. Typical Computer Output of Nitric Acid (for Ammonium Nitrate) Manufacturing Costs.

CALCULATED RESULTS ALLIS CHALMERS CELL
NAPHTHA COST IS $27.00/TON, INCOME TAX 0 CURRENT DENSITY 800

1000 TON/DAY NH3 PLANT

TABLE 5 AMMONIUM NITRATE PRODUCTION COSTS, $/TON NH4NO3, FOR 1333.8 TONS/DAY NH4NO3

		ELECTROLYSIS				NAPHTHA REFORMING			
1	RETURN ON INVESTMENT	.10	.10	.10	.10	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	1.00	2.00	4.00	8.00
	RAW MATERIALS AND UTILITIES								
4	PHOSPHATE ROCK	0	0	0	0	0	0	0	0
5	NAPHTHA OR NH3	2.62	4.45	8.12	15.44	5.99	6.13	6.43	7.01
6	ELECTRIC POWER	.03	.07	.14	.28	.03	.07	.14	.28
7	NITROGEN OR HNO3	4.03	5.96	9.84	17.57	7.61	7.77	8.09	8.72
8	COOLING WATER	.02	.02	.02	.02	.02	.02	.02	.02
9	BOILER FEEDWATER	0	0	0	0	0	0	0	0
10	CONDENSATE OR STEAM	0	0	0	0	0	0	0	0
11	SUBTOTAL	6.71	10.51	18.12	33.32	13.66	13.99	14.68	16.03
	LABOR AND SUPERVISION								
13	OPERATING LABOR	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
14	MAINTENANCE LABOR	.29	.29	.29	.29	.29	.29	.29	.29
15	OPERATING SUPERVISION	.06	.06	.06	.06	.06	.06	.06	.06
16	SUBTOTAL	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.36
	MATERIALS								
18	OPERATING SUPPLIES	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40
19	MAINTENANCE MATERIALS	.18	.18	.18	.18	.18	.18	.18	.18
20	CATALYSTS AND CHEMICALS	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
21	SUBTOTAL	8.09	8.09	8.09	8.09	8.09	8.09	8.09	8.09
22	PLANT OVERHEAD	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42
	INDIRECT COSTS								
24	RECOVERY OF INVESTMENT	1.59	1.59	1.59	1.59	1.39	1.39	1.39	1.39
25	RETURN ON INVESTMENT	5.05	5.05	5.05	5.05	4.41	4.41	4.41	4.41
26	INTEREST ON WORK. CAP.	.44	.51	.64	.91	.55	.56	.57	.59
27	SUBTOTAL	7.08	7.15	7.28	7.55	6.34	6.35	6.36	6.38
28	TOTAL MANUFACTURING COST	25.66	29.52	37.27	52.73	31.87	32.21	32.91	34.28
29	OXYGEN CREDIT	0	0	0	0	0	0	0	0
30	NET MANUFACTURING COST	25.66	29.52	37.27	52.73	31.87	32.21	32.91	34.28
31	FEDERAL INCOME TAX	0	0	0	0	0	0	0	0
32	TOTAL	25.66	29.52	37.27	52.73	31.87	32.21	32.91	34.28
	NUMBER OF OPERATORS		28.00				28.00		

Fig. 5. Typical Computer Output of Ammonium Nitrate Manufacturing Costs.

CALCULATED RESULTS, UREA PRODUCTION COSTS, BYPRODUCT CO2 SOURCE
NAPHTHA COST IS $27.00/TON, INCOME TAX 0 CURRENT DENSITY 800

THE AMMONIA PLANT PRODUCES 1000 TONS/DAY NH3, THE FRACTIONAL CAPACITY DEVOTED TO UREA PRODUCTION IS .58 OR 1000 TONS/DAY UREA

TABLE 6 BAGGED UREA PRODUCTION COSTS, $/TON UREA

		ELECTROLYTIC NH3				NAPHTHA-REFORMER NH3			
1	RETURN ON INVESTMENT	.10	.10	.10	.10	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	1.00	2.00	4.00	8.00
	RAW MATERIALS AND UTILITIES								
4	PHOSPHATE ROCK	0	0	0	0	0	0	0	0
5	NAPHTHA OR NH3	7.55	12.48	22.36	42.09	15.79	16.17	16.95	18.49
6	ELECTRIC POWER	.14	.27	.54	1.09	.14	.27	.54	1.09
7	NITROGEN OR HNO3	0	0	0	0	0	0	0	0
8	COOLING WATER	.40	.40	.40	.40	.40	.40	.40	.40
9	BOILER FEEDWATER	0	0	0	0	0	0	0	0
10	CONDENSATE OR STEAM	.14	.36	.72	1.20	.14	.36	.72	1.20
11	SUBTOTAL	8.23	13.51	24.02	44.78	16.47	17.20	18.61	21.17
	LABOR AND SUPERVISION								
13	OPERATING LABOR	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22
14	MAINTENANCE LABOR	.56	.56	.56	.56	.56	.56	.56	.56
15	OPERATING SUPERVISION	.11	.11	.11	.11	.11	.11	.11	.11
16	SUBTOTAL	2.89	2.89	2.89	2.89	2.89	2.89	2.89	2.89
	MATERIALS								
18	OPERATING SUPPLIES	6.65	6.65	6.65	6.65	6.65	6.65	6.65	6.65
19	MAINTENANCE MATERIALS	.85	.85	.85	.85	.78	.7[illegible]	.78	.78
20	CATALYSTS AND CHEMICALS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
21	SUBTOTAL	8.50	8.50	8.50	8.50	8.43	8.43	8.43	8.43
22	PLANT OVERHEAD	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73
	INDIRECT COSTS								
24	RECOVERY OF INVESTMENT	2.08	2.08	2.08	2.08	1.79	1.79	1.79	1.79
25	RETURN ON INVESTMENT	6.81	6.81	6.81	6.81	5.70	5.70	5.70	5.70
26	INTEREST ON WORK. CAP.	.53	.62	.81	1.17	.65	.66	.69	.73
27	SUBTOTAL	9.22	9.31	9.50	9.86	8.14	8.16	8.18	8.23
28	TOTAL MANUFACTURING COST	30.57	35.95	46.65	67.77	37.67	38.41	39.85	42.45
29	OXYGEN CREDIT	0	0	0	0	0	0	0	0
30	NET MANUFACTURING COST	30.57	35.95	46.65	67.77	37.67	38.41	39.85	42.45
31	FEDERAL INCOME TAX	0	0	0	0	0	0	0	0
32	TOTAL	30.57	35.95	46.65	67.77	37.67	38.41	39.85	42.45
	NUMBER OF OPERATORS		22.00				22.00		

Fig. 6. Typical Computer Output of Urea Manufacturing Costs.

CALCULATED RESULTS,NITRIC PHOSPHATE PRODUCTION COSTS
INCOME TAX 0 CURRENT DENSITY 800
NAPATHA COST $27.00/TON PHOSPHATE ROCK COST $ 9.60/TON

TABLE 5 NITRIC PHOSPHATE PRODUCTION COSTS,$/TON NITRIC PHOSPHATE OF ANALYSIS 27-14-0
NITRIC PHOSPHATE PRODUCTION RATE 1440TONS/DAY REQUIRES 500TON/DAY NH_3,TOTAL NH_3 PRODUCTION= 1000TON/DAY

		ELECTROLYSIS				NAPHTHA REFORMING			
1	RETURN ON INVESTMENT	.10	.10	.10	.10	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	1.00	2.00	4.00	8.00
	RAW MATERIALS AND UTILITIES								
4	PHOSPHATE ROCK	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30
5	NAPHTHA OR NH3	2.24	3.80	6.94	13.19	5.12	5.24	5.49	5.99
6	ELECTRIC POWER	.01	.03	.06	.11	.01	.03	.06	.11
7	NITROGEN OR HNO3	2.90	4.23	6.89	12.20	5.35	5.46	5.68	6.11
8	COOLING WATER	.04	.04	.04	.04	.04	.04	.04	.04
9	BOILER FEEDWATER	0	0	0	0	-0	-0	-0	-0
10	CONDENSATE OR STEAM	.13	.33	.66	1.10	.13	.33	.66	1.10
11	SUBTOTAL	9.62	12.73	18.88	30.94	14.96	15.40	16.23	17.66
	LABOR AND SUPERVISION								
13	OPERATING LABOR	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
14	MAINTENANCE LABOR	.38	.38	.38	.38	.38	.38	.38	.38
15	OPERATING SUPERVISION	.09	.09	.09	.09	.09	.09	.09	.09
16	SUBTOTAL	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81
	MATERIALS								
18	OPERATING SUPPLIES	6.80	6.80	6.80	6.80	6.80	6.80	6.80	6.80
19	MAINTENANCE MATERIALS	.60	.60	.60	.60	.60	.60	.60	.60
20	CATALYSTS AND CHEMICALS	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
21	SUBTOTAL	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
22	PLANT OVERHEAD	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69
	INDIRECT COSTS								
24	RECOVERY OF INVESTMENT	1.52	1.52	1.52	1.52	1.36	1.36	1.36	1.36
25	RETURN ON INVESTMENT	4.84	4.84	4.84	4.84	4.33	4.33	4.33	4.33
26	INTEREST ON WORK, CAP.	.48	.53	.64	.66	.57	.57	.59	.61
27	SUBTOTAL	6.84	6.90	7.00	7.22	6.26	6.27	6.28	6.31
28	TOTAL MANUFACTURING COST	29.46	32.62	38.88	51.15	34.21	34.66	35.51	36.96
29	OXYGEN CREDIT	0	0	0	0	0	0	0	0
30	NET MANUFACTURING COST	29.46	32.62	38.88	51.15	34.21	34.66	35.51	36.96
31	FEDERAL INCOME TAX	0	0	0	0	0	0	0	0
32	TOTAL	29.46	32.62	38.88	51.15	34.21	34.66	35.51	36.96
	NUMBER OF OPERATORS		35.00				35.00		

Fig. 7. Typical Computer Output of Nitric Phosphate Manufacturing Costs.

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CALCULATED RESULTS
INCOME TAX      0

TABLE PI   CAPITAL INVESTMENTS, MILLIONS OF $              600  TON/DAY P2O5 PLANT


                                                CAPACITY     PLANT INVESTMENT

ELECTRIC FURNACE METHOD
13   ELEC FURNACE P4                             262.01         17.494138
14   CAP COST, CONV OF P4 TO H3PO4               600.00          2.571104
    TOTAL                                                       20.065243

WET METHOD, (H2SO4)
15   CAP COST, H2SO4 PLANT                      1800.00          3.906693
16   CAP COST, WET-ACID PLANT                    600.00          5.614366
    TOTAL                                                        9.521058
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Fig. 8. Typical Computer Output of Capital Costs of Elemental Phosphorus and Phosphoric Acid Plants.

CALCULATED RESULTS
INCOME TAX   0

PHOSPHATE ROCK IS $ 9.60/TON, SULFUR COST IS $40.00/TON, BOTH PLANTS PRODUCE 600 TONS/DAY P205

COST OF PRODUCING P205 BY ELECTRIC FURNACE AND H2SO4 ACIDULATION PROCESSES

		ELECTRIC FURNACE				WET ACID			
		$/TON P205				$/TON P205			
1	RETURN ON INVESTMENT	.10	.10	.10	.10	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	1.00	2.00	4.00	8.00
RAW MATERIALS									
4	SULPHURIC ACID	0	0	0	0	46.19	46.92	46.94	46.97
5	PHOSPHATE ROCK	35.74	35.74	35.74	35.74	34.30	34.30	34.30	34.30
6	MATRIX	4.38	4.38	4.38	4.38	0	0	0	0
7	COKE	11.71	11.71	11.71	11.71	0	0	0	0
8	ELECTRODES	1.82	1.82	1.82	1.82	0	0	0	0
9	SUBTOTAL	53.64	53.64	53.64	53.64	80.49	81.22	81.26	81.27
UTILITIES									
11	ELECTRIC POWER	5.24	10.47	20.94	41.88	.30	.60	1.20	2.40
12	COOLING WATER	.22	.22	.22	.22	.10	.10	.10	.10
13	BOILER FEEDWATER	0	0	0	0	0	0	0	0
14	EXHAUST STEAM	.04	.11	.29	.48	0	0	0	0
15	SUBTOTAL	5.49	10.80	21.45	42.58	.40	.70	1.30	2.50
MAINTENANCE AND OPERATING LABOR									
17	OPERATING LABOR	4.00	4.00	4.00	4.00	3.36	3.36	3.36	3.36
18	MAINTENANCE LABOR	1.92	1.92	1.92	1.92	3.31	3.31	3.31	3.31
19	SUBTOTAL	5.92	5.92	5.92	5.92	6.67	6.67	6.67	6.67
MATERIALS									
21	OPERATING SUPPLIES	.30	.30	.30	.30	0	0	0	0
22	MAINTENANCE MATERIALS	3.44	3.44	3.44	3.44	1.65	1.65	1.65	1.65
23	CHEM., MOBILE EQUIP., LAB ANAL.	.83	.83	.83	.83	1.38	1.38	1.38	1.38
24	SUBTOTAL	4.56	4.56	4.56	4.56	3.03	3.03	3.03	3.03
26	PLANT OVERHEAD	3.55	3.55	3.55	3.55	4.00	4.00	4.00	4.00
INDIRECT COSTS									
28	RECOVERY OF INVESTMENT	2.70	2.70	2.70	2.70	.87	.87	.87	.87
29	RETURN ON INVESTMENT	8.59	8.59	8.59	8.59	2.76	2.76	2.76	2.76
30	INTEREST ON WORKING CAPITAL	1.52	1.62	1.81	2.19	1.77	1.79	1.80	1.82
31	SUBTOTAL	12.81	12.91	13.10	13.48	5.39	5.41	5.42	5.44
33	TOTAL MFG. COST (W.O. OFFSITES)	35.98	91.39	102.22	123.73	99.98	101.03	101.66	102.91
34	BYPRODUCT CREDIT	0	0	0	0	0	0	0	0
35	CONVERSION TO H3PO4	5.27	6.03	6.11	6.28	0	0	0	0
36	NET MFG. COST(W.O. OFFSITES)	91.25	97.42	108.33	130.01	99.98	101.03	101.66	102.91
NUMBER OF OPERATORS			26.00				25.00		

Fig. 9. Typical Computer Output of Elemental Phosphorus and Phosphoric Acid Manufacturing Costs.

CALCULATED RESULTS ALUMINUM PLANTS
AL2O3 COST $/TON -0 BAUXITE COST $/TON -0

TABLE I CAPITAL INVESTMENTS,MILLIONS OF $ 274 TON/DAY ALUMINUM PLANT

			CAPACITY	PLANT INVESTMENT
LOCAL ALUMINUM PLANT				
1	EXTRACTION PLANT	TONS/D AL2O3	548.00	31.155025
2	SMELTING PLANT	TONS/D ALUMINUM	274.00	69.970566
3	FABRICATION PLANT	TONS/D ALUMINUM	274.00	85.489172
4	TOTAL ALUMINUM			186.614763

Fig. 10. Typical Computer Output of Capital Costs of Alumina Refining and Aluminum Smelting and Fabrication Plants.

TABLE 2 ALUMINA PRODUCTION COSTS, $/TON AL2O3 [illegible]TON/DAY AL2O3

		LOCAL ALUMINA PLANT			
1	RETURN ON INVESTMENT,PERCENT	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00
	RAW MATERIALS				
4	BAUXITE	17.60	17.60	17.60	17.60
5	SODIUM HYDROXIDE	2.63	2.63	2.63	2.63
6	CALCIUM HYDROXIDE	.60	.60	.60	.60
7	ALUMINA	0	0	0	0
8	ELECTROLYTE	0	0	0	0
9	ELECTRODE AND POT MATERIALS	0	0	0	0
10	ALUMINUM (MOLTEN)	0	0	0	0
11	SUBTOTAL	20.83	20.83	20.83	20.83
	UTILITIES				
13	POWER	.20	.40	.80	1.60
14	PROCESS WATER	.08	.10	.25	.42
15	PRIME STEAM	.36	.90	1.80	3.00
16	FUEL	5.00	5.00	5.00	5.00
17	SUBTOTAL	5.62	6.40	7.85	10.02
	MAINTENANCE AND OPERATING LABOR				
19	OPERATING LABOR	2.10	2.10	2.10	2.10
20	MAINTENANCE LABOR	0	0	0	0
21	OPERATING SUPERVISION	.23	.23	.23	.23
22	SUBTOTAL	2.33	2.33	2.33	2.33
	MATERIALS				
24	OPERATING SUPPLIES	.60	.60	.60	.60
25	MAINTENANCE MATERIALS	3.04	3.04	3.04	3.04
26	CATAYSTS AND CHEMICALS	.10	.10	.10	.10
27	SUBTOTAL	3.74	3.74	3.74	3.74
29	PLANT OVERHEAD	1.40	1.40	1.40	1.40
	INDIRECT COSTS				
31	RECOVERY OF INVESTMENT	4.78	4.78	4.78	4.78
32	RETURN ON INVESTMENT	15.19	15.19	15.19	15.19
33	INTEREST ON WORKING CAPITAL	.95	.95	.99	1.03
34	SUBTOTAL	20.92	20.94	20.96	21.00
36	TOTAL MFG.COST (W.O.OFFSITES)	54.83	55.63	57.11	59.31
37	BYPRODUCT CREDIT	0	0	0	0
38	NET MFG.COST(W.O.OFFSITES)	54.83	55.63	57.11	59.31
	NUMBER OF OPERATORS		12.00		

Fig. 11. Typical Computer Output of Alumina Refining Costs.

CALCULATED RESULTS ALUMINUM PLANTS
TON/D AL PLANT 274 BAUXITE COST $/TON 8.00

TABLE 3 ALUMINUM SMELTING COSTS,$/TON AL 274TON/DAY AL

		LOCAL ALUMINUM PLANT			
1	RETURN ON INVESTMENT,PERCENT	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00
	RAW MATERIALS				
4	BAUXITE	0	0	0	0
5	SODIUM HYDROXIDE	0	0	0	0
6	CALCIUM HYDROXIDE	0	0	0	0
7	ALUMINA	65.45	66.95	69.76	73.94
8	ELECTROLYTE	10.20	10.20	10.20	10.20
9	ELECTRODE AND POT MATERIALS	31.52	31.52	31.52	31.52
10	ALUMINUM (MOLTEN)	0	0	0	0
11	SUBTOTAL	107.17	108.65	111.46	115.66
	UTILITIES				
13	POWER	13.00	26.00	52.00	104.00
14	PROCESS WATER	0	0	0	0
15	PRIME STEAM	.10	.24	.48	.80
16	FUEL	.98	.93	.98	.98
17	SUBTOTAL	14.07	27.22	53.46	105.78
	MAINTENANCE AND OPERATING LABOR				
19	OPERATING LABOR	22.07	22.07	22.07	22.07
20	MAINTENANCE LABOR	11.46	11.45	11.46	11.46
21	OPERATING SUPERVISION	2.60	2.60	2.60	2.60
22	SUBTOTAL	36.13	36.13	36.13	36.13
	MATERIALS				
24	OPERATING SUPPLIES	0	0	0	0
25	MAINTENANCE MATERIALS	12.81	12.81	12.81	12.81
26	CATAYSTS AND CHEMICALS	0	0	0	0
27	SUBTOTAL	12.81	12.81	12.81	12.81
29	PLANT OVERHEAD	21.68	21.63	21.68	21.68
	INDIRECT COSTS				
31	RECOVERY OF INVESTMENT	29.72	29.72	29.72	29.72
32	RETURN ON INVESTMENT	64.03	64.03	64.03	64.03
33	INTEREST ON WORKING CAPITAL	5.03	5.29	5.80	6.79
34	SUBTOTAL	98.78	99.03	99.54	100.54
36	TOTAL MFG.COST (W.O.OFFSITES)	290.64	305.55	335.10	392.60
37	BYPRODUCT CREDIT	0	0	0	0
38	NET MFG.COST(W.O.OFFSITES)	290.64	305.55	335.10	392.60

NUMBER OF OPERATORS 63.00

Fig. 12. Typical Computer Output of Aluminum Smelting Costs.

CALCULATED RESULTS ALUMINUM PLANTS
TON/D AL PLANT 274 BAUXITE COST $/TON 8.00

TABLE 4 ALUMINUM FABRICATION COSTS,$/TON AL 274TON/DAY AL

		LOCAL ALUMINUM PLANT			
1	RETURN ON INVESTMENT,PERCENT	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00
	RAW MATERIALS				
4	BAUXITE	0	0	0	0
5	SODIUM HYDROXIDE	0	0	0	0
6	CALCIUM HYDROXIDE	0	0	0	0
7	ALUMINA	0	0	0	0
8	ELECTROLYTE	0	0	0	0
9	ELECTRODE AND POT MATERIALS	0	0	0	0
10	ALUMINUM (MOLTEN)	194.74	209.61	239.09	296.44
11	SUBTOTAL	194.74	209.61	239.09	296.44
	UTILITIES				
13	POWER	1.20	2.40	4.80	9.60
14	PROCESS WATER	.84	1.44	3.60	6.00
15	PRIME STEAM	0	0	0	0
16	FUEL	5.00	5.00	5.00	5.00
17	SUBTOTAL	7.04	8.84	13.40	20.60
	MAINTENANCE AND OPERATING LABOR				
19	OPERATING LABOR	55.01	55.01	55.01	55.01
20	MAINTENANCE LABOR	0	0	0	0
21	OPERATING SUPERVISION	0	0	0	0
22	SUBTOTAL	55.01	55.01	55.01	55.01
	MATERIALS				
24	OPERATING SUPPLIES	0	0	0	0
25	MAINTENANCE MATERIALS	17.17	17.17	17.17	17.17
26	CATAYSTS AND CHEMICALS	.75	.75	.75	.75
27	SUBTOTAL	17.92	17.92	17.92	17.92
29	PLANT OVERHEAD	33.00	33.00	33.00	33.00
	INDIRECT COSTS				
31	RECOVERY OF INVESTMENT	47.15	47.15	47.15	47.15
32	RETURN ON INVESTMENT	149.81	149.81	149.81	149.81
33	INTEREST ON WORKING CAPITAL	8.89	9.18	9.78	10.92
34	SUBTOTAL	205.85	206.14	206.74	207.88
36	TOTAL MFG.COST (W.O.OFFSITES)	513.56	530.53	565.16	630.86
37	BYPRODUCT CREDIT	0	0	0	0
38	NET MFG.COST(W.O.OFFSITES)	513.56	530.53	565.16	630.86

NUMBER OF OPERATORS 157.00

Fig. 13. Typical Computer Output of Aluminum Fabrication Costs.

CALCULATED RESULTS CHLORINE-CAUSTIC PLANTS

TABLE 1 CAPITAL INVESTMENTS, MILLIONS OF $ 1000 TON/DAY CHLORINE PLANT AND 6873 TON/DAY SOLAR SALT PLANT

		CAPACITY	PLANT INVESTMENT	
LOCAL CHLORINE-CAUSTIC PLANT				U.S. CHLORINE-CAUSTIC PLANT
SOLAR EVAPORATION PLANT	TONS/DAY NACL	6873.33	8.756733	
CHLORINE-CAUSTIC ELECT. PLANT	TONS/DAY CL2	1000.00	18.493587	18.493587
CAUSTIC PRODUCTION PLANT	TONS/DAY NAOH	1130.00	5.791297	5.791297
HYDROCHLORIC ACID PRODUCTION PLANT	TONS/DAY HCL	1030.00	.371898	

Fig. 14. Typical Computer Output of Capital Costs of a 9000-ton/day Solar Salt Works.

CALCULATED RESULTS CHLORINE-CAUSTIC PRODUCTION

TABLE 2 SALT PRODUCTION COSTS, $/TON NACL FOR A 6873 TON/DAY SOLAR EVAPORATION PLANT

1	RETURN ON INVESTMENT,PERCENT	.10	.10	.10	.10	0	0	0	0
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	0	0	0	0
	RAW MATERIALS								
4	SALT, BRINE, OR NAOH	0	0	0	0	0	0	0	0
5	SUBTOTAL	0	0	0	0	0	0	0	0
	UTILITIES								
7	POWER	.00	.01	.02	.03	0	0	0	0
8	COOLING WATER	0	0	0	0	0	0	0	0
9	STEAM	0	0	0	0	0	0	0	0
10	SUBTOTAL	.00	.01	.02	.03	0	0	0	0
	MAINTENANCE AND OPERATING LABOR								
12	OPERATING LABOR	.14	.14	.14	.14	0	0	0	0
13	MAINTENANCE AND RENEWAL LABOR	0	0	0	0	0	0	0	0
14	OPERATING SUPERVISION	0	0	0	0	0	0	0	0
15	SUBTOTAL	.14	.14	.14	.14	0	0	0	0
	MATERIALS								
17	OPERATING SUPPLIES	.19	.19	.19	.19	0	0	0	0
18	MAINTENANCE MATERIALS	.19	.19	.19	.19	0	0	0	0
19	CATALYSTS AND CHEMICALS	0	0	0	0	0	0	0	0
20	RENEWAL MATERIALS	0	0	0	0	0	0	0	0
21	SUBTOTAL	.38	.38	.38	.38	0	0	0	0
23	PLANT OVERHEAD	.08	.08	.08	.08	0	0	0	0
	INDIRECT COSTS								
25	RECOVERY OF INVESTMENT	.12	.12	.12	.12	0	0	0	0
26	RETURN ON INVESTMENT	.38	.38	.38	.38	0	0	0	0
27	INTEREST ON WORKING CAPITAL	.02	.02	.02	.02	0	0	0	0
28	SUBTOTAL	.52	.52	.52	.52	0	0	0	0
30	TOTAL MFG. COST(W.O.OFFSITES)	1.13	1.14	1.14	1.16	0	0	0	0
32	BYPRODUCT SODIUM HYDROXIDE CREDI	0	0	0	0	0	0	0	0
33	BYPRODUCT HCL CREDIT	0	0	0	0	0	0	0	0
34	NET MFG.COST(W.O.OFFSITES)	1.13	1.14	1.14	1.16	0	0	0	0
35	FEDERAL INCOME TAX	0	0	0	0	0	0	0	0
36	TOTAL	1.13	1.14	1.14	1.16	0	0	0	0

NUMBER OF OPERATORS 176 0

Fig. 15. Typical Computer Output of Manufacturing Costs of a 9000-ton/day Solar Salt Works.

CALCULATED RESULTS CHLORINE-CAUSTIC PRODUCTION
INCOME TAX 0

1000 TON/DAY CHLORINE PLANT WITH NAOH PRODUCTION OF 1130 TON/DAY
SALT COST IS $ 1.38 PER TON

TABLE 3 CHLORINE PRODUCTION COSTS, $/TON CL2

		LOCAL CL2 PLANT				U. S. PLANT			
1	RETURN ON INVESTMENT,PERCENT	.10	.10	.10	.10	.10	.10	.10	.10
2	POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	4.50	4.50	4.50	4.50
	RAW MATERIALS								
4	SALT, BRINE, OR NAOH	2.54	2.55	2.57	2.60	1.85	1.85	1.85	1.85
5	SUBTOTAL	2.54	2.55	2.57	2.60	1.85	1.85	1.85	1.85
	UTILITIES								
7	POWER	3.20	6.40	12.80	25.60	14.40	14.40	14.40	14.40
8	COOLING WATER	.30	.30	.30	.30	.30	.30	.30	.30
9	STEAM	.02	.06	.15	.25	.50	.50	.50	.50
10	SUBTOTAL	3.52	6.76	13.25	26.15	15.20	15.20	15.20	15.20
	MAINTENANCE AND OPERATING LABOR								
12	OPERATING LABOR	.58	.58	.58	.58	.58	.58	.58	.58
13	MAINTENANCE AND RENEWAL LABOR	.95	.96	.96	.96	.96	.96	.96	.96
14	OPERATING SUPERVISION	.12	.12	.12	.12	.12	.12	.12	.12
15	SUBTOTAL	1.65	1.66	1.66	1.66	1.66	1.66	1.66	1.66
	MATERIALS								
17	OPERATING SUPPLIES	.70	.70	.70	.70	.70	.70	.70	.70
18	MAINTENANCE MATERIALS	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
19	CATALYSTS AND CHEMICALS	.30	.30	.30	.30	.30	.30	.30	.30
20	RENEWAL MATERIALS	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40
21	SUBTOTAL	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57
23	PLANT OVERHEAD	.99	.99	.99	.99	.99	.99	.99	.99
	INDIRECT COSTS								
25	RECOVERY OF INVESTMENT	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68
26	RETURN ON INVESTMENT	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
27	INTEREST ON WORKING CAPITAL	.38	.43	.55	.77	.57	.57	.57	.57
28	SUBTOTAL	7.39	7.44	7.56	7.79	7.58	7.58	7.58	7.58
30	TOTAL MFG. COST(W.O.OFFSITES)	21.67	24.98	31.60	44.75	32.85	32.85	32.85	32.85
	NUMBER OF OPERATORS			7				7	

Fig. 16. Typical Computer Output of Caustic-Chlorine Manufacturing Costs by Brine Electrolysis.

CALCULATED RESULTS CHLORINE-CAUSTIC PRODUCTION
INCOME TAX 0

TABLE 4 COST OF NAOH PRODUCTION FOR MARKET,$/TON NAOH

1000 TON/DAY CHLORINE PLANT WITH PRODUCTION OF 1130 TON/DAY NAOH AND 1030 TON/DAY HCL

	LOCAL CL2 PLANT				U. S. PLANT			
1 RETURN ON INVESTMENT,PERCENT	.10	.10	.10	.10	.10	.10	.10	.10
2 POWER COST (AC) MILLS/KWH	1.00	2.00	4.00	8.00	4.50	4.50	4.50	4.50
RAW MATERIALS								
4 SALT, BRINE, OR NAOH	19.18	22.10	27.96	39.61	29.07	29.07	29.07	29.07
5 SUBTOTAL	19.18	22.10	27.96	39.61	29.07	29.07	29.07	29.07
UTILITIES								
7 POWER	.10	.20	.40	.80	.45	.45	.45	.45
8 COOLING WATER	.20	.20	.20	.20	.20	.20	.20	.20
9 STEAM	.13	.39	.98	1.63	3.25	3.25	3.25	3.25
10 SUBTOTAL	.43	.79	1.58	2.63	.65	.65	.65	.65
MAINTENANCE AND OPERATING LABOR								
12 OPERATING LABOR	.17	.17	.17	.17	.17	.17	.17	.17
13 MAINTENANCE AND RENEWAL LABOR	0	0	0	0	0	0	0	0
14 OPERATING SUPERVISION	0	0	0	0	0	0	0	0
15 SUBTOTAL	.17	.17	.17	.17	.17	.17	.17	.17
MATERIALS								
17 OPERATING SUPPLIES	0	0	0	0	0	0	0	0
18 MAINTENANCE MATERIALS	.30	.30	.30	.30	.30	.30	.30	.30
19 CATALYSTS AND CHEMICALS	0	0	0	0	0	0	0	0
20 RENEWAL MATERIALS	0	0	0	0	0	0	0	0
21 SUBTOTAL	.30	.30	.30	.30	.30	.30	.30	.30
23 PLANT OVERHEAD	.10	.10	.10	.10	.10	.10	.10	.10
INDIRECT COSTS								
25 RECOVERY OF INVESTMENT	.47	.47	.47	.47	.47	.47	.47	.47
26 RETURN ON INVESTMENT	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48
27 INTEREST ON WORKING CAPITAL	.39	.45	.56	.79	.57	.57	.57	.57
28 SUBTOTAL	2.33	2.39	2.51	2.73	2.51	2.51	2.51	2.51
30 TOTAL MFG. COST(W.O.OFFSITES)	22.51	25.85	32.61	45.53	32.80	32.80	32.80	32.80
NUMBER OF OPERATORS			2				2	

Fig. 17. Typical Computer Output of 50% Caustic Evaporation Costs.

TABLE 1. MAJOR RAW MATERIALS AND COMPLEX REQUIREMENTS

	UNITS/YEAR	$/YEAR
PHOSPHATE ROCK, TON/YR.	3241109	31114643
MATRIX-PHOSPHORUS PLANT, TON/YR.	952526	3810103
BAUXITE, TON/YR	825484	6603872
FUEL-ALUMINUM PLANTS, MMBTU/YR	3758342	1879171
TOTAL COOLING WATER, MGPM	75	
TOTAL POWER USED BY COMPLEX, MWH/YR.	15142468	
PEAK POWER LOAD, MW	1981	
POWER COST/YR. FOR TWO MILL/KWH POWER		32284935
PRIME STEAM CONSUMPTION, MMBTU/YR.	2726747	
PEAK PRIME STEAM CONSUMPTION, MWT	98	
TOTAL NUMBER OF LABORERS	2940	
TOTAL OVERHEAD, $/YR.		11289785

Fig. 18. Typical Computer Output for Raw Material and Utility Requirements of an Industrial-Only Complex.

TABLE 2 INDUSTRIAL COMPLEX
INTEREST RATE .100

PRODUCT VALUE

	PLANT	PLANT SIZE TONS/DAY	MILLIONS OF DOLLARS LOCAL	IMPORTED	R.I. PLANT INVEST. AT VARIOUS POWER COSTS, MILLS/KWH 1.00	2.00	4.00	8.00	ANNUAL COST OF PRODUCTION $/TON	$/YEAR
5	NITROGEN PRODUCTION	2520	0	- 0	0	0	0	0	-0	-0
7	ELECTROLYTIC NH3	3000	58.972	-.000	12377012	20274684	36098689	67689376	30	31207500
13	ELEC FURNACE P4	1120	56.624	- 0	58281515	62906169	72172018	90571372	109	94905128
20	CAUSTIC-CHLORINE	1000	18.888	-.000	7877456	9000926	11251333	15724408	50	17337500
27		514	0	0	0	0	0	0	-0	-0
31	FABRICATED ALUMINUM	514	247.169	- 0	52408142	55536346	61922206	74033150	760	142583600
	SUBTOTAL, DIRECT COSTS		391.653	-.000	130944126	147718124	181444246	248018307		
	INDIRECT COSTS									
	RECOVERY + RETURN ON INVESTMENT				50740192	50740192	50740192	50740192		
	AVERAGE WORKING CAPITAL, INTEREST		40.778		3235814	3542244	4158283	5374774		
	SUBTOTAL, INDIRECT COSTS		40.778		53976006	54282436	54898475	56114966		
	INDUSTRIAL SERVICES		28.256	7.064	4643717	4643717	4643717	4643717		
	TOTALS FOR COMPLEX		460.687	7.064	189563849	206644277	240986439	308776990		286033728

THE TURNOVER RATIO FOR THIS COMPLEX IS .67

FIXED MANUFACTURING COSTS FOR THIS COMPLEX (WITHOUT COSTS OF POWER AND PRIME STEAM) ARE $ 114638053/YEAR.

Fig. 19. Typical Computer Output of Capital Costs, Annual Cost of Production, Annual Value of Product, and Turnover Ratio of an Industrial-Only Complex.

3. SUMMARY OF COST DATA FOR MAKING INDUSTRIAL BUILDING BLOCK AND COMPLEXING COST STUDIES

This section is a compilation of tables which will permit the interested reader easily and rapidly to obtain any industrial manufacturing cost calculated in the computer studies. When used with discretion, appropriate linear extrapolation of values will permit the evaluation of costs for the full range of all parameters that were considered. Better extrapolations of nonlinear functions can be achieved, however, by using the tabular data for plotting the required graphs; in almost all cases the tabulated data are sufficient for plotting large-scale graphs. For a complete explanation of the data, Chap. 5 of ORNL-4290 should be consulted.

To obtain the gross manufacturing cost of any product the four direct costs (raw materials, utilities, labor and overhead, and other materials) and the indirect costs are obtained from the tables and summed; the interest on working capital (I_{wc}) is then obtained from the equation

$$I_{wc} = \frac{S}{(365E/60i) - 1},$$

where S is the prior sum, i is cost of money as a decimal fraction, and E is the plant on-stream efficiency, also as a decimal fraction. Gross manufacturing cost is finally obtained by adding this value to the prior sum S. The on-stream efficiency for hydrogen, ammonia, ammonia derivatives, aluminum, and caustic-chlorine is 0.95; for phosphorus and phosphoric acid, 0.93; and for solar salt, 0.91.

An index to all the tables precedes the tables. At the top of each table the product whose costs are presented is given first. Costs are tabulated for each of the five cost components in the same order as previously given.

Raw materials costs of primary electric furnace phosphorus, alumina, and chlorine are functions only of naphtha, phosphate rock, bauxite, and salt costs respectively. Raw materials costs for hydrogen and solar salt are zero. Utilities costs are generally a function of power cost only. Labor costs and the costs of other materials are functions of plant capacity only, and the indirect costs are functions of plant size and cost of money.

It was decided to present these cost tables for component costs rather than for total manufacturing costs, because it is believed that presentation in this manner gives a better appreciation of the various costs; in addition, presentation in this form requires somewhat less space. The amount of arithmetic required to obtain any manufacturing cost is very slight.

With a small amount of additional data the information in Tables 11 through 31 can be used to compute costs for a United States industrial complex producing any or all of the listed products. Such a complex is exclusive of a nuclear reactor, seawater evaporator, or food factory; a full discussion of the inclusion of these facilities is given in Chap. 7 of the main report (ORNL-4290).

The additional information required includes (1) Table 2, which is a summary of the capital costs of all plants at their reference capacities; (2) Fig. 20, which is a plot of the off-site costs vs total battery limits capital investment costs for all of the production plants in a complex; and (3) Table 10, which presents the product values (for both United States and non-United States conditions) used in the complexing studies.

To determine the annual manufacturing costs of a United States complex, the direct costs for each plant at the desired capacity are first determined from the appropriate tables, summed, and then multiplied by the annual production rate. The annual

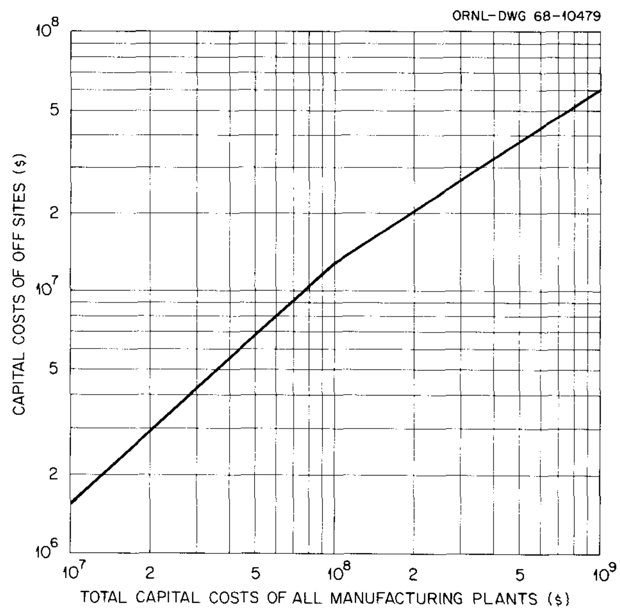

Fig. 20. Off-Sites Capital Costs as a Function of Total Plant Capital Costs.

direct costs for all plants are then summed. The same procedure is then repeated for the indirect costs, and the interest on working capital is computed as described earlier, using a "complex" on-stream efficiency of 94%.

In order to determine the capital cost of off-site facilities the capital costs of all battery limits plants included in the complex are obtained for the appropriate capacities and summed. In case extrapolation of these values is required, logarithmic rather than linear extrapolations should be made. Where a product is made in several steps, as, for example, fabricated aluminum from alumina refining, aluminum smelting, and finally aluminum fabrication, the capital costs for all process steps are included. The investment in off-sites is then obtained from Fig. 20. Finally, the indirect costs associated with the investment in off-site facilities are obtained by using Eqs. (2) and (3).

Total manufacturing cost for the complex is determined as the sum of the annual direct costs and indirect costs (including interest on working capital) of all production plants plus the indirect costs of the off-site facilities. Income from sale of products from the complex is found as the product of the annual tonnage times its sale price (from Table 10) for each product; total complex income is the summation of all individual product incomes.

In those complexes in which both ammonia and chlorine are produced, the hydrogen from brine electrolysis is assumed to be used in the production of additional ammonia. Thus, if the quantity of both products is fixed, the hydrogen requirements from water electrolysis or steam-naphtha reforming are reduced accordingly, along with the appropriate capital and operating costs.

In the case of production of ammonia from reformed hydrogen, no air liquefaction plant to provide nitrogen is included since the nitrogen is assumed to be available from the reformer off-gases. When nitric acid is produced, the use of the nitric acid tail gases as a source of nitrogen is optional; thus the requirement for an air liquefaction plant is mandatory only when ammonia (but not nitric acid) is produced from electrolytic hydrogen.

When secondary ammonia products are made, the amount of salable ammonia is reduced by the amount converted to secondary products. A list of the amounts of ammonia required for the various secondary processes is contained in Table 5.

The conversion of industrial complex costs to non-United States conditions cannot be done exactly with the data presented so far, but approximations can be made. These approximations can be improved if particular care is taken in the conversion of raw materials costs. To provide a better understanding of the conversion process, each of the cost components will be discussed individually.

Raw material prices assumed for United States and non-United States locations are listed in Table 10, part A. Utilities costs for United States and non-United States cases are the same if power (water and steam) rates are unchanged; if changed, the costs can be converted linearly. Labor and overhead costs will, in general, be reduced. In the cases evaluated it was assumed that the non-United States labor cost was \$0.67 per hour (vs \$4.00 per hour for the United States) but that three times as much labor was required. This results in a comparative non-United States labor cost of \$2.00 per United States man-hour (\$0.67 $\times$ 3), half the total labor cost under United States conditions. Overhead was 60% of total labor in both cases. The cost of supplies and other materials is increased but by different amounts for different products. Since this item is generally a small fraction of total costs, an average increase of 10% may be taken.

With regard to plant capital costs, the United States cost for each plant was divided into two parts: the part of the total cost of plant and equipment which could be obtained from indigenous sources and the part which must be imported. Each part is then multiplied by an appropriate conversion factor, and the modified costs are recombined to give the equivalent non-United States plant investment cost. In our studies a conversion factor of 1.00 was generally used for the local or indigenous part and 1.2 for the imported part, thereby resulting in a non-United States capital cost between 1.0 and 1.2 times the corresponding United States costs. Off-site capital costs were determined in the same way that they were for United States complexes. Similarly, indirect costs for both plants and off sites were determined as before, using the non-United States capital costs.

Table 10. Assumed Raw Material Costs and Product Sales Prices

A. Raw Material Costs

Material	Cost (dollars/ton)[a]
Naphtha	15, 22, 27, 35
Elemental phosphorus	
Phosphate rock	5.50, 9.60, 17, 24 (19)
Sulfur	32, 50, 65, 80
Aluminum	
Bauxite	3, 8, 11, 14 (5.50)
Alumina	60, 77
Caustic–chlorine	
Salt	1, 3, 6, 10

B. Product Sales Prices

Product	Product Sales Price[b] (dollars/ton)	
	United States Price	Non-United States Price
Fabricated Aluminum	740[c]	800
Ammonia	30	45
Phosphorus	229	300
Chlorine	50	*d*
Caustic	*d*	80
Urea	60	75
Ammonium Nitrate	50	65
Nitric Phosphate[e]	60	80
Solar Salt	*d*	4

[a]Typical values used in evaluating product manufacturing costs: those values that are singly underlined were assumed representative of United States locations; doubly underlined values are typical of non-United States locations.

[b]F.o.b. factory.

[c]The price used in ORNL-4290 was $650 per ton; however, this price is too low to give a reasonable return on investment in the fabrication facility.

[d]Assumed to have no value because of marketing considerations.

[e]Product analysis: N, 27%; P_2O_5, 14%; K_2O, 0.

Table 11. Electrolytic Hydrogen from Allis-Chalmers Cells

Costs in dollars per ton of equivalent NH_3 (0.18 ton of H_2 = 1 ton of NH_3); one ton of ammonia requires 66,700 ft^3 (std) of hydrogen (standard conditions, dry gas at 60°F and 1 atm)

I. Direct Costs

A. Raw Materials Costs

No cost for raw materials

B. Utilities Costs

As a function of power cost and current density

Current Density (amp/ft^2)	Cost for Power Cost of –			
	1 mill/kwhr	2 mills/kwhr	4 mills/kwhr	8 mills/kwhr
400	7.46	14.88	29.72	59.41
800	7.83	15.60	31.15	62.25
1200	8.34	16.59	33.11	66.13
1600	8.89	17.68	35.25	70.40

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of –			
	300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
Labor	0.98[a]	0.49[a]	0.29[a]	0.29[b]
Overhead	0.59	0.29	0.18	0.18
Total	1.57	0.78	0.47	0.47

D. Costs of Other Materials

As a function of plant capacity and current density

Current Density (amp/ft^2)	Cost for Plant Capacity of –			
	300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
400	1.57	1.49	1.43	1.32
800	1.28	1.22	1.17	1.08
1200	1.14	1.08	1.04	0.96
1600	1.05	0.99	0.96	0.88

Table 11 (continued)

II. Indirect Costs

As a function of plant capacity, current density, and cost of money

Current Density (amp/ft^2)	Cost of Money, i (%)	Cost for Plant Capacity of –			
		300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
400	2.5	5.76	5.46	5.26	4.83
	5	6.88	6.52	6.27	5.76
	10	9.39	8.90	8.55	7.86
	20	15.27	14.47	13.91	12.79
800	2.5	4.71	4.47	4.30	3.95
	5	5.62	5.33	5.12	4.71
	10	8.68	7.27	6.99	6.42
	20	12.48	11.82	11.37	10.45
1200	2.5	4.18	3.97	3.82	3.51
	5	5.00	4.74	4.55	4.19
	10	6.82	6.47	6.22	5.71
	20	11.10	10.52	10.11	9.29
1600	2.5	3.85	3.65	3.51	3.22
	5	4.60	4.36	4.18	3.85
	10	6.27	5.95	5.72	5.25
	20	10.20	9.67	9.30	8.55

[a]One operator per shift.
[b]Three operators per shift.

Table 12. Electrolytic Hydrogen from General Electric Cells

Costs in dollars per ton of equivalent NH_3 (0.18 ton of H_2 = 1 ton of NH_3)
Plant size: 180 tons/day

I. Direct Costs

A. Raw Materials Costs

No cost for raw materials

B. Utilities Costs

As a function of power cost and current density

Current Density (amp/ft^2)	Cost for Power Cost of – 1 mill/kwhr	2 mills/kwhr	4 mills/kwhr	8 mills/kwhr
1750	5.72	11.48	23.01	46.07
2500	6.39	12.80	25.62	51.25
3500	7.30	14.56	29.09	58.16
5000	8.65	17.20	34.31	68.52
7500	10.90	21.60	42.99	85.78

C. Labor and Overhead Costs

Labor and overhead costs: \$0.29 labor[a] plus \$0.18 overhead = \$0.47 per ton of NH_3

D. Costs of Other Materials

As a function of current density and cell material cost

Cell Material Cost (dollars/ft^2)	Cost for Current Density of – 1750 amp/ft^2	2500 amp/ft^2	3500 amp/ft^2	5000 amp/ft^2	7500 amp/ft^2
25	0.73	0.69	0.65	0.63	0.61
50	0.90	0.80	0.73	0.69	0.65
100	1.22	1.03	0.90	0.80	0.72

II. Indirect Costs

As a function of current density, cell material cost, and cost of money

Cell Material Cost (dollars/ft^2)	Cost of Money, i (%)	Cost for Current Density[b] of – 1750 amp/ft^2	2500 amp/ft^2	3500 amp/ft^2	5000 amp/ft^2	7500 amp/ft^2
25	2.5	2.69	2.52	2.40	2.30	2.24
	5	3.22	3.00	2.87	2.76	2.68
	10	4.39	4.10	3.90	3.76	3.64
	20	7.14	6.67	6.35	6.12	5.94
50	2.5	3.29	2.94	2.69	2.52	2.38
	5	3.93	3.50	3.22	3.00	2.84
	10	5.36	4.77	4.39	4.10	3.88
	20	8.72	7.77	7.14	6.67	6.30
100	2.5	4.49	3.77	3.29	2.94	2.65
	5	5.35	4.49	3.93	3.50	3.17
	10	7.30	6.14	5.36	4.77	4.43
	20	11.88	9.99	8.72	7.77	7.04

[a]One operator per shift.

[b]To maintain isothermal operation of the General Electric cell at 1100°C, a certain minimum current density must be maintained so that I^2r heating can provide the endothermic heat of reaction for the water decomposition; for the configuration described here the minimum current density is about 3500 amp/ft^2.

Table 13. Electrolytic Hydrogen from Advanced De Nora Cells

Plant size: 180 tons/day; current density: 300 amp/ft^2

Item	Cost (dollars per ton of equivalent NH_3)[a]
Raw materials costs	
No cost for raw materials	
Utilities costs	
Power cost of:	
1 mill/kwhr	7.74
2 mills/kwhr	15.44
4 mills/kwhr	30.82
8 mills/kwhr	61.60
Labor and overhead costs	
Labor[b]	0.29
Overhead	0.18
Total	0.47
Costs of other materials	1.21
Indirect costs	
Cost of money, i, of:	
2.5%	4.43
5%	5.28
10%	7.20
20%	11.72

[a]66,700 ft^3 of hydrogen per ton of NH_3 (standard conditions, dry gas at 60°F and 1 atm pressure).
[b]One operator per shift.

Table 14. Nitrogen for Ammonia Synthesis

Manufacturing cost of nitrogen in dollars per ton of NH_3 as a function of plant capacity and cost of money
Source of nitrogen is an air liquefaction plant with recovery of 50% of the incoming air as a clean product
$A = 0.180 \times$ power cost in mills per kilowatt-hour, and this quantity must be added to the listed costs

Cost of Money, i (%)	Cost for Ammonia Plant Size of –			
	300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
2.5	1.93 + A	1.44 + A	1.20 + A	0.87 + A
5	2.12 + A	1.59 + A	1.33 + A	0.96 + A
10	2.56 + A	1.95 + A	1.64 + A	1.17 + A
20	3.60 + A	2.78 + A	2.34 + A	1.67 + A

Table 15. Ammonia from Electrolytic Hydrogen: Allis-Chalmers Cells

Costs in dollars per ton of NH_3. Includes all costs associated with the electrolytic hydrogen plant

I. Direct Costs

A. Raw Materials Costs

For cost of nitrogen required, see Table 14

B. Utilities Costs[a]

As a function of power cost and current density

Current Density (amp/ft^2)	Cost for Power Cost of –			
	1 mill/kwhr	2 mills/kwhr	4 mills/kwhr	8 mills/kwhr
400	8.38	16.35	32.32	64.18
800	8.75	17.07	33.75	67.02
1200	9.26	18.06	35.70	70.90
1600	9.82	19.15	37.84	75.17

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of –			
	300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
Labor	2.49	1.25	0.75	0.65
Overhead	1.50	0.75	0.45	0.39
Total	3.99	2.00	1.20	1.04

D. Costs of Other Materials

As a function of plant capacity and current density

Current Density (amp/ft^2)	Cost for Plant Capacity of –			
	300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
400	2.46	2.23	2.10	1.89
800	2.17	1.96	1.83	1.64
1200	2.03	1.82	1.70	1.53
1600	1.94	1.74	1.62	1.45

Table 15 (continued)

II. Indirect Costs

As a function of plant capacity, current density, and cost of money

Current Density (amp/ft^2)	Cost of Money, i (%)	Cost for Plant Capacity of —			
		300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
400	2.5	7.81	7.19	6.77	5.98
	5	9.32	8.58	8.08	7.14
	10	12.72	11.70	11.02	9.74
	20	20.69	19.04	17.93	15.84
800	2.5	6.76	6.19	5.82	5.10
	5	8.07	7.39	6.93	6.09
	10	11.00	10.08	9.46	8.31
	20	17.90	16.39	15.39	13.50
1200	2.5	6.24	5.69	5.34	4.66
	5	7.44	6.79	6.36	5.56
	10	10.15	9.26	8.69	7.59
	20	16.51	15.07	14.13	12.34
1600	2.5	5.90	5.37	5.03	4.38
	5	7.04	6.41	5.99	5.23
	10	9.60	8.74	8.19	7.13
	20	15.62	14.23	13.31	11.60

[a]Includes 525 kwhr/ton for compression of synthesis gas to 3000 psi.

Table 16. Ammonia from Electrolytic Hydrogen: General Electric Cells

Costs in dollars per ton of NH_3. Includes all costs associated with the electrolytic hydrogen plant
Plant size: 1000 tons/day of NH_3
Cell costs are based on a cost of $100.00 per square foot of active electrode surface

I. Direct Costs

A. Raw Materials Costs

For cost of nitrogen required, see Table 14

B. Utilities Costs[a]

As a function of power cost and current density

Current Density (amp/ft^2)	Cost for Power Cost of –			
	1 mill/kwhr	2 mills/kwhr	4 mills/kwhr	8 mills/kwhr
1750	7.16	13.98	27.65	54.94
2500	7.83	15.30	30.26	60.12
3500	8.73	17.06	33.73	67.03
5000	10.08	19.70	38.94	77.39
7500	12.34	24.10	47.63	94.65

C. Labor and Overhead Costs

Labor and overhead costs: $0.75 labor plus $0.45 overhead = $1.20 per ton of NH_3

D. Costs of Other Materials

As a function of current density

Current Density (amp/ft^2)	Cost
1750	1.97
2500	1.78
3500	1.65
5000	1.55
7500	1.47

II. Indirect Costs

As a function of current density and cost of money

Current Density (amp/ft^2)	Cost for Cost of Money, i, of –			
	2.5%	5%	10%	20%
1750	6.36	7.58	10.35	16.82
2500	5.63	6.72	9.18	14.93
3500	5.16	6.15	8.40	13.67
5000	4.81	5.73	7.82	12.72
7500	4.52	5.40	7.36	11.98

[a]Includes 1038 kwhr/ton for compression of hydrogen and nitrogen to 3000 psi.

Table 17. Ammonia from Electrolytic Hydrogen: Advanced De Nora Cells

Includes all costs associated with the electrolytic hydrogen plant
Plant size: 1000 tons/day of NH_3; current density: 300 amp/ft^2

Item	Cost (dollars per ton of NH_3)
Raw materials costs	
For cost of nitrogen required, see Table 14	
Utilities costs[a]	
Power cost of:	
1 mill/kwhr	9.18
2 mills/kwhr	17.93
4 mills/kwhr	35.46
8 mills/kwhr	70.46
Labor and overhead costs	
Labor[b]	0.75
Overhead	0.45
Total	1.20
Costs of other materials	1.96
Indirect costs	
Cost of money, *i*, of:	
2.5%	6.30
5%	7.51
10%	10.24
20%	16.66

[a]Includes 1083 kwhr/ton for compression of synthesis gas from atmospheric pressure to 3000 psi.
[b]Two operators per shift.

Table 18. Ammonia by Steam-Naphtha Reforming

Costs in dollars per ton of NH_3

I. Direct Costs

A. Raw Materials Costs

Raw materials cost: 0.80 times naphtha cost (dollars/ton)

B. Utilities Costs

As a function of power cost

Power Cost (mills/kwhr)	Cost
1	1.63
2	2.30
4	3.64
8	6.28

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of –			
	300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
Labor	2.49[a]	1.25[a]	0.75[a]	0.65[b]
Overhead	1.50	0.75	0.45	0.39
Total	3.99	2.00	1.20	1.04

D. Costs of Other Materials

As a function of plant capacity

Plant Capacity (tons/day of NH_3)	Cost
300	2.71
600	2.34
1000	2.14
3000	1.83

II. Indirect Costs

As a function of plant capacity and cost of money

Cost of Money, *i* (%)	Cost for Plant Capacity of –			
	300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
2.5	6.13	5.01	4.30	3.13
5	7.32	5.97	5.14	3.72
10	9.98	8.15	7.01	5.09
20	16.23	13.25	11.41	8.27

[a]Two operators per shift.
[b]Five operators per shift.

Table 19. Nitric Acid Production

Costs in dollars per ton of nitric acid

I. Direct Costs

A. Raw Materials Costs

Raw materials cost: 0.29 times cost of ammonia (dollars/ton)

B. Utilities Costs

Power (5 kwhr/ton): 0.005 times cost of power (mills/kwhr)
Cooling water (23,000 gal/ton): 0.23 times cost of cooling water (cents/1000 gal)
Boiler feedwater (340 gal/ton): 0.0034 times cost of boiler feedwater (cents/1000 gal)

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of –			
	320 tons/day	640 tons/day	1067 tons/day	3201 tons/day
Labor	0.87[a]	0.43[a]	0.26[a]	0.26[b]
Overhead	0.52	0.26	0.16	0.16
Total	1.39	0.69	0.42	0.42

D. Costs of Other Materials

As a function of plant capacity

Plant Capacity (tons/day)	Cost
320	0.88
640	0.77
1067	0.70
3201	0.61

II. Indirect Costs

As a function of plant capacity and cost of money
Indirect costs are computed for a nitric acid plant sending tail gases to an ammonia synthesis plant (provides nitrogen). Thus the plant is increased in size by about 8%. To obtain the indirect costs for a normal-size plant, multiply by 0.923. The direct operating costs are not changed appreciably

Cost of Money, i (%)	Cost for Plant Capacity of –			
	320 tons/day	640 tons/day	1067 tons/day	3201 tons/day
2.5	1.77	1.39	1.17	0.81
5	2.10	1.66	1.39	0.96
10	2.87	2.26	1.91	1.31
20	4.66	3.69	3.10	2.14

[a]One operator per shift.
[b]Three operators per shift.

Table 20. Ammonium Nitrate Production

Costs in dollars per ton of ammonium nitrate

I. Direct Costs

A. Raw Materials Costs

Cost for ammonia:[a] 0.22 times cost of ammonia (dollars/ton)
Cost for nitric acid: 0.80 times cost of nitric acid (100%, dollars/ton)

B. Utilities Costs

Power (35 kwhr/ton): 0.035 times cost of power (mills/kwhr)
Cooling water (12,000 gal/ton): 0.12 times cost of cooling water (cents/1000 gal)
Steam (1,250,000 Btu/ton): 0.0125 times cost of steam (cents/MMBtu)

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of —			
	400 tons/day	800 tons/day	1334 tons/day	4001 tons/day
Labor[b]	2.71[c]	2.58[d]	2.36[e]	1.95[f]
Overhead	1.63	1.55	1.42	1.17
Total	4.34	4.13	3.78	3.12

D. Costs of Other Materials

As a function of plant capacity
Includes: bags (30¢ each), $6.30; catalyst, $0.40

Plant Capacity (tons/day)	Cost
400	8.19
800	8.13
1334	8.09
4001	8.01

II. Indirect Costs

As a function of plant capacity and cost of money

Cost of Money, i (%)	Cost for Plant Capacity of —			
	400 tons/day	800 tons/day	1334 tons/day	4001 tons/day
2.5	1.10	0.88	0.74	0.52
5	1.31	1.04	0.89	0.62
10	1.79	1.43	1.21	0.85
20	2.92	2.33	1.98	1.38

[a]Total amount of ammonia needed is 0.452 ton of ammonia per ton of ammonium nitrate.
[b]Includes labor for bagging entire plant output.
[c]10 operators per shift.
[d]18 operators per shift.
[e]28 operators per shift.
[f]70 operators per shift.

Table 21. Urea Production (Bagged)

Costs in dollars per ton of urea

Assumes electrolytic hydrogen used in ammonia process; therefore all costs associated with capital investment are somewhat higher because of inclusion of additional carbon dioxide purification equipment in the investment (see Fig. 4)

I. Direct Costs

A. Raw Materials Costs

Cost for ammonia: 0.58 times cost of ammonia (dollars/ton)

Cost for carbon dioxide:[a] 0.75 times cost of carbon dioxide (dollars/ton)

Cost for conditioner (0.02 ton at $50.00 per ton): $1.00

B. Utilities Costs

Assumes electric compressor drives

Electricity (129 kwhr/ton): 0.129 times cost of electricity (mills/kwhr)

Cooling water (26,600 gal/ton): 0.266 times cost of cooling water (cents/1000 gal)

Steam (2.2 MMBtu/ton): 0.022 times cost of steam (150 psig, cents/MMBtu)

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of —			
	300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
Labor	3.94[b]	3.50[c]	2.89[d]	2.10[e]
Overhead	2.36	2.10	1.73	1.26
Total	6.30	5.60	4.62	3.36

D. Costs of Other Materials

As a function of plant capacity

Includes: bags (30¢ each), $6.30; maintenance materials at 3% of capital investment

Plant Capacity (tons/day)	Cost
300	8.95
600	8.67
1000	8.50
3000	8.23

Table 21 (continued)

II. Indirect Costs

As a function of plant capacity and cost of money

Cost of Money, i (%)	Cost for Plant Capacity of –			
	300 tons/day	600 tons/day	1000 tons/day	3000 tons/day
2.5	3.49	2.75	2.30	1.58
5	4.16	3.28	2.74	1.87
10	5.68	4.47	3.75	2.56
20	9.24	7.27	6.10	4.17

[a] If carbon dioxide is not available as a waste product, it can be obtained by calcination of calcium carbonate in a kiln. Assume production of 900 tons of carbon dioxide (14,688,000 SCF) per day. The installed capital investment for a plant of this capacity is estimated to be as follows:

Direct-indirect electrically heated kiln	$1,800,000
Recovery system (assuming 80% feed gas concentration)	370,000
Total	$2,170,000

Operating costs, in cents per thousand standard cubic feet of carbon dioxide, are estimated to be as follows:

Raw materials costs	280 times cost of calcium carbonate (cents/lb)
Utilities (electricity, 147 kwhr/MSCF)	14.7 times cost of electricity (mills/kwhr)
Other costs	3¢
Indirect costs for cost of money, i, of:	
2.5%	3.6¢
5%	4.3¢
10%	5.9¢
20%	9.6¢

[b] 9 operators per shift, not including men for bagging operation (0.69 man-hour per ton).

[c] 16 operators per shift, not including men for bagging operation (0.69 man-hour per ton).

[d] 22 operators per shift, not including men for bagging operation (0.69 man-hour per ton).

[e] 48 operators per shift, not including men for bagging operation (0.69 man-hour per ton).

Table 22. Nitric Phosphate Production (Odda Process)

Costs in dollars per ton of nitric phosphate fertilizer analyzing 27-14-0. Actual production is 60% nitric phosphate (23-23-0) and 40% ammonium nitrate (33.5-0-0); the fertilizer with analysis 27-14-0 is a composite of these two fertilizers

I. Direct Costs

A. Raw Materials Costs

Cost for phosphate rock:[a] 0.45 times cost of phosphate rock (dollars/ton)
Cost for nitric acid: 0.55 times cost of nitric acid (100%, dollars/ton)
Cost for ammonia: 0.19 times cost of ammonia (dollars/ton)
Cost for carbon dioxide: 0.021 times cost of carbon dioxide (cents/MSCF)

B. Utilities Costs

Electricity (14 kwhr/ton): 0.014 times cost of electricity (mills/kwhr)
Cooling water (2000 gal/ton): 0.02 times cost of cooling water (cents/1000 gal)
Steam (2.14 MMBtu/ton): 0.0214 times cost of steam (cents/MMBtu)

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of —			
	450 tons/day	900 tons/day	1500 tons/day	4501 tons/day
Labor[b]	7.68	5.40	4.32	2.52
Overhead	4.61	3.24	2.59	1.51
Total	12.29	8.64	6.91	4.03

D. Costs of Other Materials

As a function of plant capacity
Includes: plastic bags (30¢ each), $6.30; maintenance materials at 4% of capital investment

Plant Capacity (tons/day)	Cost
450	8.74
900	8.59
1500	8.49
4501	8.33

Table 22 (continued)

II. Indirect Costs

As a function of plant capacity and cost of money

Cost of Money, i (%)	Cost for Plant Capacity of –			
	450 tons/day	900 tons/day	1500 tons/day	4501 tons/day
2.5	1.70	1.39	1.19	0.86
5	2.03	1.65	1.42	1.02
10	2.77	2.25	1.94	1.40
20	4.50	3.66	3.14	2.27

[a]Assumed analysis: 33% P_2O_5.
[b]Breakdown of labor requirements as a function of plant capacity:

Item	Man-Hours per Ton for Plant Capacity of –			
	450 tons/day	900 tons/day	1500 tons/day	4501 tons/day
Operating and supervision	0.77	0.46	0.27	0.11
Storage, shipping, and bagging	0.88	0.71	0.71	0.45
Maintenance labor	0.27	0.18	0.10	0.07
Total	1.92	1.35	1.08	0.63

Table 23. Elemental Phosphorus Production by the Electric Furnace Process

Costs in dollars per ton of equivalent P_2O_5 (2.29 tons of P_2O_5 is equivalent to 1.0 ton of elemental phosphorus)

I. Direct Costs

A. Raw Materials Costs[a]

Cost for phosphate rock:[b] 3.72 times cost of phosphate rock (dollars/ton)
Cost for matrix: 1.10 times cost of matrix (dollars/ton)[c]
Cost for coke:[d] 0.60 times cost of coke (dollars/ton)[e]
Cost for electrodes: 13 times cost of electrodes (dollars/lb)[f]

B. Utilities Costs

Electricity (5240 kwhr/ton):[g] 5.24 times cost of electricity (mills/kwhr)
Steam (1.9 MMBtu/ton): 0.019 times cost of steam (cents/MMBtu)
Cooling water (11,000 gal/ton): 0.11 times cost of cooling water (cents/1000 gal)

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity[h] of –			
	300 tons/day	600 tons/day	1500 tons/day	3435 tons/day
Operating labor	8.00[i]	4.00[i]	1.96[j]	1.03[k]
Maintenance labor	3.84	1.92	1.38	1.12
Overhead	7.10	3.55	2.00	1.29
Total	18.94	9.47	5.34	3.44

D. Costs of Other Materials

As a function of plant capacity and system of feed preparation

Plant Capacity[h] (tons/day)	Cost	
	Pelletized Feed Preparation System	Nodulized Feed Preparation System
300	7.15	6.21
600	5.29	4.61
1500	4.65	3.89
3435	4.30	3.48

II. Indirect Costs

As a function of plant capacity, cost of money, and system of feed preparation

Feed Preparation System	Cost of Money, i (%)	Cost for Plant Capacity[h] of –			
		300 tons/day	600 tons/day	1500 tons/day	3435 tons/day
Pelletized	2.5	11.58	8.41	7.38	6.79
	5	13.81	10.03	8.80	8.10
	10	18.85	13.68	12.01	11.05
	20	30.66	22.26	19.53	17.98
Nodulized	2.5	9.68	7.02	5.84	5.12
	5	11.94	8.37	6.96	6.11
	10	16.29	11.42	9.50	8.33
	20	26.50	18.59	15.46	13.56

Table 23 (continued)

III. By-Product Credits

Credit for ferrophosphorus: yield of ferrophosphorus[l] times \$40.00[m]

Credit for slag: 3 to 4 times \$1.00[m]

[a]The analyses assumed for the numbers given in the raw materials costs section are as follows:

Constituent	Percent, Dry Basis	
	Rock	Matrix
P_2O_5	31.1	
CaO	46.5	
Al_2O_3	1.0	
Fe_2O_3	1.7	1.0
SiO_2	9.5	99.0
F	3.7	

[b]The amount of phosphate rock required is a function of the analyses of the rock and the matrix. The presence of iron in the furnace burden leads to losses of phosphorus as ferrophosphorus, and the amount of these losses can be calculated as follows:

$$L = 0.6864 \frac{x_R + Mx_M}{100} ,$$

where L is the equivalent weight of P_2O_5 lost as ferrophosphorus per ton of phosphate rock feed, M is the weight of matrix needed per ton of rock to give an SiO_2/CaO ratio of 0.83 in the furnace burden, x_R is the percentage of Fe_2O_3 in the rock, and x_M is the percentage of Fe_2O_3 in the matrix.

The total weight W of P_2O_5 that must be charged to the furnace to yield 1 ton of phosphorus (as P_2O_5) is

$$W = 1.144 + L ;$$

that is, other losses amount to 14.4%.

[c]Matrix cost of \$1.00 per ton used in study. See *Nuclear Energy Centers: Industrial and Agro-Industrial Complexes*, ORNL-4290 (November 1968).

[d]The amount of coke needed to reduce the furnace charge is 103% of the theoretical amount required to reduce all the phosphorus and iron according to the reactions:

$$2P_2O_5 + 10C \longrightarrow P_4 + 10CO ,$$

$$Fe_2O_3 + 3C \longrightarrow 2Fe + 3CO ,$$

assuming 89% available carbon in the coke.

[e]Coke cost of \$17.00 per ton used in study. See ORNL-4290.

[f]Electrode cost of \$0.14 per pound used in study. See ORNL-4290.

[g]1087 kwhr used per ton of rock plus matrix charged to the furnace.

[h]Plant capacity in tons of P_2O_5 per day. Corresponding capacities in tons of P_4 per day are as follows:

P_2O_5	P_4
300	131
600	262
1500	656
3435	1500

[i]Number of operating personnel per shift: 26.

[j]Number of operating personnel per shift: 32.

[k]Number of operating personnel per shift: 47.

[l]The yield of ferrophosphorus in tons per ton of phosphorus product (as P_2O_5) is $1.4556WL$ (see footnote *b*).

[m]Typical price per ton.

Table 24. Conversion of Elemental Phosphorus to Phosphoric Acid

Total of direct and indirect costs in dollars per ton of P_2O_5
As a function of power cost, plant capacity, and cost of money

Cost of Money, i (%)	Plant Capacity (tons/day)[a]	Cost for Power Cost of –			
		1 mill/kwhr	2 mills/kwhr	4 mills/kwhr	8 mills/kwhr
2.5	300	6.14	6.18	6.26	6.42
	600	5.34	5.38	5.46	5.62
	1500	4.71	4.75	4.83	4.99
	3435	4.17	4.21	4.29	4.45
5	300	6.37	6.41	6.49	6.66
	600	5.52	5.57	5.65	5.81
	1500	4.84	4.89	4.97	5.13
	3435	4.28	4.32	4.40	4.56
10	300	6.94	6.98	7.06	7.23
	600	5.99	6.03	6.11	6.28
	1500	5.21	5.25	5.33	5.49
	3435	4.60	4.65	4.73	4.89
20	300	8.42	8.46	8.54	8.71
	600	7.24	7.28	7.36	7.53
	1500	6.20	6.24	6.33	6.49
	3435	5.47	5.51	5.59	5.76

[a]Tons of P_2O_5 per day.

Table 25. Phosphoric Acid Production by the Wet Acid Process

Costs in dollars per ton of P_2O_5

I. Direct Costs

A. Raw Materials Costs

Cost for phosphate rock:[a] 3.57 times cost of phosphate rock (dollars/ton)
Cost for sulfuric acid:[b] 2.96 times cost of acid (98%, dollars/ton)[c]

B. Utilities Costs

Electricity (300 kwhr/ton): 0.30 times cost of power (mills/kwhr)
Cooling water (22,000 gal/ton): 0.22 times cost of cooling water (cents/1000 gal)
Boiler feedwater (1000 gal/ton): 0.010 times cost of boiler feedwater (cents/1000 gal)

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of –			
	300 tons/day	600 tons/day	1500 tons/day	3435 tons/day
Labor	10.90[d]	6.67[d]	4.03[e]	2.65[f]
Overhead	6.54	4.00	2.42	1.59
Total	17.44	10.67	6.45	4.24

D. Costs of Other Materials

As a function of plant capacity

Plant Capacity (tons/day)	Cost
300	3.83
600	3.03
1500	2.23
3435	1.68

II. Indirect Costs

As a function of plant capacity and cost of money

Cost of Money, i (%)	Cost for Plant Capacity of –			
	300 tons/day	600 tons/day	1500 tons/day	3435 tons/day
2.5	2.81	2.23	1.64	1.23
5	3.35	2.66	1.95	1.48
10	4.58	3.36	2.66	2.01
20	7.44	5.89	4.33	3.27

[a]Assumes that the rock analyzes 31.1% P_2O_5 and that recovery is 90%.

[b]The amount of sulfuric acid is computed as follows:

$$A = 1.772Rx_R\ ,$$

where A is the number of tons of 98% H_2SO_4 required per ton of P_2O_5, R is the number of tons of phosphate rock required per ton of P_2O_5, and x_R is the percentage of CaO in the rock.

[c]A good approximation to the manufacturing cost of sulfuric acid is the following, valid for plants in the range from 250 to 1000 tons:

$$C_A = 0.333P_S + 2.50 \pm 0.75\ ,$$

where C_A is the manufacturing cost of sulfuric acid (100%, dollars/ton) and P_S is the cost of sulfur (dollars/ton).

[d]25 operators per shift.

[e]27 operators per shift.

[f]31 operators per shift.

Table 26. Alumina Production from Bauxite

Costs in dollars per ton of Al_2O_3

I. Direct Costs

A. Raw Materials Costs

Cost for bauxite: 2.20[a] times cost of bauxite (dollars/ton)
Cost for caustic soda: 0.071 times cost of caustic soda (dollars/ton)[b]
Cost for lime: 0.03 times cost of lime (dollars/ton)[c]

B. Utilities Costs

Electricity (200 kwhr/ton): 0.20 times cost of electricity (mills/kwhr)
Steam (6.0 MMBtu/ton): 0.060 times cost of steam (cents/MMBtu)
Process water (850 gal/ton): 0.0085 times cost of process water (cents/1000 gal)
Fuel (10 MMBtu/ton): 0.10 times cost of fuel (cents/MMBtu)[d]

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of –		
	100,000 tons/year	200,000 tons/year	500,000 tons/year
Labor	2.72[e]	2.33[f]	1.86[g]
Overhead	1.63	1.40	1.12
Total	4.35	3.73	2.98

D. Costs of Other Materials

As a function of plant capacity

Plant Capacity (tons/year)	Cost
100,000	4.10
200,000	3.74
500,000	3.32

II. Indirect Costs

As a function of plant capacity and cost of money

Cost of Money, i (%)	Cost for Plant Capacity of –		
	100,000 tons/year	200,000 tons/year	500,000 tons/year
2.5	13.73	12.27	10.57
5	16.38	14.64	12.62
10	22.35	19.97	17.22
20	36.36	32.50	28.01

[a]The amount of bauxite required is a function of reactive silica and alumina content. This value assumes a bauxite containing about 50% Al_2O_3 and 1% reactive silica.

[b]Caustic soda cost of $35.00 per ton used in the energy center study. See ORNL-4290.

[c]Lime cost of $20.00 per ton used in the energy center study. See ORNL-4290.

[d]Fuel cost of 50¢/MMBtu used in the energy center study. See ORNL-4290.

[e]7 operators per shift.

[f]12 operators per shift.

[g]24 operators per shift.

Table 27. Molten Aluminum Production from Alumina

Costs in dollars per ton of molten aluminum

I. Direct Costs

A. Raw Materials Costs

Cost for alumina: 1.93 times cost of alumina (dollars/ton)
Cost for electrolyte: $10.20[a]
Cost for electrode and pot materials: $31.52[b]

B. Utilities Costs

1. Söderberg Anodes (<150 tons/day)

Electricity (13,800 kwhr/ton): 13.8 times cost of electricity (mills/kwhr)
Steam (1.61 MMBtu/ton): 0.0161 times cost of steam (cents/MMBtu)

2. Prebaked Anodes (>150 tons/day)

Electricity (13,000 kwhr/ton): 13.0 times cost of electricity (mills/kwhr)
Steam (1.61 MMBtu/ton): 0.0161 times cost of steam (cents/MMBtu)
Fuel (1.95 MMBtu/ton): 0.0195 times cost of fuel (cents/MMBtu)[c]

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity[d] of –		
	137 tons/day	274 tons/day	685 tons/day
Labor	42.44[e]	36.13[f]	28.68[g]
Overhead	25.47	21.68	17.21
Total	67.91	57.81	45.89

D. Costs of Other Materials

As a function of plant capacity
Consists mainly of maintenance materials for pot relining

Plant Capacity[d] (tons/day)	Cost
137	14.60
274	12.81
685	10.77

II. Indirect Costs

For a plant life of 15 years
As a function of plant capacity and cost of money

Cost of Money, i (%)	Cost for Plant Capacity[d] of –		
	137 tons/day	274 tons/day	685 tons/day
2.5	58.96	51.85	43.53
5	70.33	61.84	51.92
10	95.97	84.39	70.85
20	156.13	137.29	115.26

Table 27 (continued)

[a]Breakdown of electrolyte composition and cost (prices are those used in ORNL-4290):

Constituent	Tons per Ton of Aluminum		Price
	Söderberg Anodes	Prebaked Anodes	(dollars/ton)
Aluminum fluoride	0.04	0.031	230
Cryolite	0.023	0.013	220
Fluorspar	0.0006	0.0005	35
Soda ash	0.001	0.0009	40

[b]Electrode and pot materials include the following (prices are those used in ORNL-4290):

Item	Tons per Ton of Aluminum		Price
	Söderberg Anodes	Prebaked Anodes	(dollars/ton)
Calcined petroleum coke	0.37	0.41	40
Coal tar pitch	0.18	0.12	81
Calcined anthracite coal	0.008	0.004	7
Prebaked cathode blocks	0.013	0.014	7

[c]Fuel cost of 50¢/MMBtu used in ORNL-4290.

[d]Corresponding capacities in tons per year are as follows:

Tons per Day	Tons per Year
137	50,000
274	100,000
685	250,000

[e]60 operators per shift.

[f]103 operators per shift.

[g]205 operators per shift.

Table 28. Fabrication of Aluminum into Sheet, Plate, and Redraw Rod

Costs in dollars per ton of fabricated aluminum

70% of the production is sheet and plate, and the remainder is rod

I. Direct Costs

A. Raw Materials Costs

Cost for aluminum: 1.015 times cost of aluminum (dollars/ton)

B. Utilities Costs

Electricity (1200 kwhr/ton): 1.2 times cost of electricity (mills/kwhr)

Water (12,000 gal/ton): 0.12 times cost of water (¢/1000 gal)

Fuel oil (70 gal/ton): 0.70 times cost of fuel oil (¢/gal)[a]

Natural gas (10 MMBtu/ton): 0.10 times cost of natural gas (¢/MMBtu)[b]

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity[c] of –		
	137 tons/day	274 tons/day	685 tons/day
Labor[d]	67.27[e]	55.01[f]	42.60[g]
Overhead	40.36	33.00	25.56
Total	107.63	88.01	68.16

D. Costs of Other Materials

As a function of plant capacity

Plant Capacity[c] (tons/day)	Cost
137	26.37
274	18.17
685	14.50

II. Indirect Costs

As a function of plant capacity and cost of money

Cost of Money, i (%)	Cost for Plant Capacity[c] of –		
	137 tons/day	274 tons/day	685 tons/day
2.5	64.94	44.75	35.72
5	77.46	53.37	42.60
10	105.70	72.83	58.14
20	171.96	118.49	94.58

[a]Suggested price, 7¢/gal.

[b]Suggested price, 30¢/MMBtu.

[c]Corresponding capacities in tons per year are as follows:

Tons per Day	Tons per Year
137	50,000
274	100,000
685	250,000

[d]25% are maintenance personnel.

[e]Number of operating personnel per shift: 96.

[f]Number of operating personnel per shift: 157.

[g]Number of operating personnel per shift: 304.

Table 29. Salt Production from Seawater by Solar Evaporation

Costs in dollars per ton of salt

Salt production in tons per acre per year varies quite widely depending on the type of soil, the age of the pond, and whether soil preconditioning has been performed. The concentration ratio of the seawater also affects the production rate for a given area of land. Preconditioning of the soil with a 2% concrete mixture probably obviates any beneficial effects of pond aging; however, it is expensive. An approximate relationship giving production rate as a function of seawater concentration ratio and time of pond aging is given in the headnote to Table 1

I. Direct Costs

A. Raw Materials Costs

Ordinarily there would be no cost for raw materials; however, if the feed to the plant was concentrated seawater rejected by a desalting evaporator, a small charge might be necessary

B. Utilities Costs

Electricity (17 kwhr/ton): 0.017 times cost of electricity (mills/kwhr)

C. Labor and Overhead Costs

Labor: since labor cost for a solar evaporation facility is very dependent on local labor rates, only a manpower requirement is listed[a]

Overhead: 60% of labor cost

D. Costs of Other Materials

As a function of plant capacity

Plant Capacity[b] (tons/day)	Cost
3,000	0.73
9,000	0.35
15,000	0.25

II. Indirect Costs[c]

As a function of plant capacity and cost of money

Cost of Money, i (%)	Cost for Plant Capacity[b] of –		
	3000 tons/day	9000 tons/day	15,000 tons/day
2.5	0.42	0.19	0.16
5	0.58	0.28	0.23
10	0.94	0.46	0.39
20	1.73	0.86	0.74

[a]Manpower requirement as a function of plant capacity:

Plant Capacity (tons/day)	Number of Operating Personnel	Man-Hours per Ton
3,000	100	0.19
9,000	220	0.14
15,000	300	0.12

Table 29 (continued)

[b]Corresponding capacities in tons per year are as follows:

Tons per Day	Tons per Year
3,000	1,000,000
9,000	3,000,000
15,000	5,000,000

[c]The indirect costs are computed assuming that 20% of the capital investment (excluding land cost) is comprised of machinery with a 10-year investment life and that the remaining 80% consists of land improvements with a 40-year life. The respective capital recovery factors based on these assumptions are:

Cost of Money, i (%)	Capital Recovery Factor
2.5	0.05428
5	0.07247
10	0.1140
20	0.2078

The cost of land assumed for the indirect costs shown above is $50.00 per acre. The assumed seawater concentration factor is 1.0, and the assumed age of the pond is three years; according to the formula in the headnote to Table 1, the production rate corresponding to these values is

$$P = e^{0.46 \times 1}(3.68 \times 3 + 15.78) = 42.5 \text{ tons per acre per year .}$$

The capital investment for the 3,000,000-ton/year plant can then be computed from the formula given in Table 1:

$$C = 3 \times 50/42.5 + 7.15 \times 3^{0.32} = \$13.69 \text{ million .}$$

The capital recovery factor is only applied to the depreciating portion of the investment, namely $7.15 \times 3^{0.32} =$ $10.16 million, with the straight cost of money applied to the land cost (no depreciation).

The depreciating investment shown here and in the table assumes minimum earth-moving operations to create the ponds and no soil conditioning, that is, ideal land for a salt recovery operation.

Table 30. Production of Chlorine by Brine Electrolysis in Diaphragm Cells

Costs in dollars per ton of chlorine

These costs are for a plant without a caustic soda concentrator

I. Direct Costs

A. Raw Materials Costs

Cost for salt: 3.65 times cost of salt (dollars/ton)[a]

B. Utilities Costs

Electricity (3200 kwhr/ton): 3.2 times cost of electricity (mills/kwhr)

Cooling water (15,000 gal/ton): 0.15 times cost of water (¢/1000 gal)

Steam (1 MMBtu/ton): 0.01 times cost of steam (¢/MMBtu)

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of –			
	300 tons/day	500 tons/day	1000 tons/day	2000 tons/day
Labor	2.64[b]	2.16[c]	1.66[d]	1.37[e]
Overhead	1.58	1.30	0.99	0.82
Total	4.22	3.46	2.65	2.19

D. Costs of Other Materials

As a function of plant capacity

Consists of: cell renewal materials, $3.40; operating materials and chemicals, $1.00; maintenance materials at 2.2% of capital investment

Plant Capacity (tons/day)	Cost
300	5.84
500	5.72
1000	5.57
2000	5.44

II. Indirect Costs

As a function of plant capacity and cost of money

Cost of Money, i (%)	Cost for Plant Capacity of –			
	300 tons/day	500 tons/day	1000 tons/day	2000 tons/day
2.5	5.28	4.84	4.30	3.84
5	6.30	5.78	5.14	4.57
10	8.60	7.89	7.01	6.23
20	13.98	12.82	11.41	10.15

[a]The high salt requirement is due to the absence of any salt recycle from a caustic concentrator.

[b]Number of operating personnel per shift: 7.

[c]Number of operating personnel per shift: 9.

[d]Number of operating personnel per shift: 13.

[e]Number of operating personnel per shift: 20.

Table 31. Production of Chlorine and Caustic Soda by Brine Electrolysis in Diaphragm Cells

Costs in dollars per co-ton (1.0 ton of Cl_2 and 1.13 tons of NaOH)
These costs include evaporator facilities for caustic soda production

I. Direct Costs

A. Raw Materials Costs

Cost for salt: 1.85 times cost of salt (dollars/ton)

B. Utilities Costs

Electricity (3250 kwhr/ton): 3.25 times cost of electricity (mills/kwhr)
Cooling water (25,000 gal/ton): 0.25 times cost of cooling water (¢/1000 gal)
Steam (4.25 MMBtu/ton): 0.0425 times cost of steam (¢/MMBtu)

C. Labor and Overhead Costs

As a function of plant capacity

Item	Cost for Plant Capacity of –			
	300 tons/day	500 tons/day	1000 tons/day	2000 tons/day
Labor	3.28[a]	2.54[b]	1.85[c]	1.56[d]
Overhead	1.97	1.52	1.11	0.94
Total	5.25	4.06	2.96	2.50

D. Costs of Other Materials

As a function of plant capacity
Consists of: cell renewal materials, \$3.40; operating materials and chemicals, \$1.00; maintenance materials at 2.2% of capital investment

Plant Capacity (tons/day)	Cost
300	6.27
500	6.12
1000	5.91
2000	5.72

II. Indirect Costs

As a function of plant capacity and cost of money

Cost of Money, *i* (%)	Cost for Plant Capacity of –			
	300 tons/day	500 tons/day	1000 tons/day	2000 tons/day
2.5	7.07	6.43	5.66	4.98
5	8.43	7.67	6.75	5.94
10	11.50	10.46	9.21	8.10
20	18.71	17.02	14.98	13.18

[a]Number of operating personnel per shift: 9.
[b]Number of operating personnel per shift: 11.
[c]Number of operating personnel per shift: 15.
[d]Number of operating personnel per shift: 24.

4. EXAMPLES

The following are seven worked examples illustrating use of the tabular data of this report. The examples were picked to illustrate several industrial processes, the technique used to build up an industrial complex, and the procedure for converting United States costs to a non-United States location.

Example 1. Compare the cost of manufacturing ammonia at a capacity of 1000 tons/day by using electrolytic hydrogen from Allis-Chalmers cells operated at 800 amp/ft^2 in an area where power costs 2 mills/kwhr with ammonia from steam-naphtha reforming in an area where power is 4 mills/kwhr and naphtha costs $22.00 per ton. Assume a 10% cost of money.

Cost Component	Electrolytic Ammonia (Table 15)		Reformer Ammonia (Table 18)	
Raw materials		$ 2.00[a]		$17.60
Utilities		17.07		3.64
Labor and overhead		1.20		1.20
Other materials		1.83		2.14
Total direct costs	$22.10		$24.58	
Indirect costs		9.46		7.01
Total, S	$31.56		$31.59	
Interest on working capital[b]		0.56		0.56
Manufacturing cost[c]	$32.12		$32.15	

[a]Nitrogen, Table 14.

[b]Interest on working capital $= S/[(365E/60i) - 1]$; $E = 0.95$.

[c]Indirects include allowance for battery limits plant only; for total manufacturing cost, the indirect costs associated with the off-site facilities must be added.

Example 2. Compare the manufacturing cost of phosphoric acid by the electric furnace and wet acid processes in an area where the power cost is 4 mills/kwhr and the costs of sulfur and phosphate rock are \$40.00 and \$9.60 per ton respectively. Assume that the cost of money, i, is 10%, that both plants produce 1500 tons of P_2O_5 equivalent per day, and that the elemental phosphorus plant has a pelletizing feed preparation system.

Cost Component	Cost (dollars per ton of P_2O_5) Electric Furnace Process (Tables 23 and 24)		Wet Acid Process (Table 25)	
Raw material				
Phosphate rock		35.71		34.27
Silica matrix		1.10		
Coke		10.20		
Electrodes		1.82		
Sulfuric acid				46.83
Total	48.83		81.10	
Utilities				
Electricity		20.96		1.20
Steam		0.57		
Cooling water		0.22		0.44
Boiler feedwater				0.50
Total	21.75		2.14	
Labor and overhead		5.34		6.45
Other materials		4.65		2.23
Total direct costs	80.57		91.92	
Indirect costs		12.01		2.66
Total	92.58		94.58	
By-product credit		5.53[a]		
Manufacturing cost of P_4	87.05			
Conversion to H_3PO_4		6.11		
Interest on working capital		1.68		1.70
Total manufacturing cost	94.84		96.28	

[a]Based on a yield of 3 tons of slag per ton of P_2O_5 and ferrophosphorus credit assuming use of phosphate rock with the analysis shown in footnote *a* of Table 23.

Example 3. Compare the manufacturing costs of fabricated aluminum from plants A and B, both of which produce 685 tons/day; plant A is located in an area where bauxite costs \$8.00 per ton and power costs 4 mills/kwhr, while plant B uses imported alumina at \$77.00 per ton and power costs 2 mills/kwhr. Cost of money for both plants is 10%.

Cost Component	Cost (dollars per ton of aluminum)			
	Plant A (Tables 26, 27, 28)		Plant B (Tables 27, 28)	
Raw material		82.85		193.18
Utilities		85.78		39.36
Labor and overhead		120.58		114.74
Cost of other materials		31.93		25.43
Total direct costs	321.14		372.71	
Indirect costs		163.78		130.05
Total, S	484.92		502.76	
Interest on working capital[a]		8.10		8.40
Manufacturing cost[b]	493.02[c]		511.16[d]	

[a]Interest on working capital = $S/[(365E/60i) - 1]$; $E = 1.00$.

[b]Fabricated shapes are: sheet and plate – 72% of total production; redraw rod – 28% of total production (footnote *g* of Table 1). Manufacturing cost includes indirect costs associated with battery limits plants only; indirects associated with off-sites must be added to obtain total manufacturing cost.

[c]Manufacturing cost \$51.97 per ton of Al_2O_3 (from Table 27) and \$322.99 per ton of molten aluminum (from Table 27).

[d]Manufacturing cost of molten aluminum is \$345.06 (from Table 27).

Example 4. In plant A urea is produced from ammonia made from electrolytic hydrogen in Allis-Chalmers cells operated at 700 amp/ft^2 using power at 2.5 mills/kwhr. In plant B urea is made from ammonia using hydrogen from steam-naphtha reforming using naphtha costing $25.00 per ton and power at 4.5 mills/kwhr. Both plants produce 1000 tons/day of urea and operate at 10% cost of money. Compare the production costs of bagged urea from plants A and B.

Cost Component	Cost (dollars per ton of ammonia)			
	Electrolysis (Table 15)		Naphtha Reforming (Table 18)	
Step 1: Determine the cost of ammonia by the two routes				
Raw materials		2.09		20.00
Utilities		25.24[a]		3.97
Labor and overhead		1.20		1.20
Cost of other materials		1.90		2.14
Total direct costs	30.43		27.31	
Indirect costs		9.85		7.01
Manufacturing cost	40.28		34.32	
Step 2: Determine the manufacturing cost of urea (Table 21)				
Raw materials				
Ammonia		23.36		19.90
Carbon dioxide		9.02[b]		
Conditioner		1.00		1.00
Utilities		1.27		0.85
Labor and overhead		4.62		4.62
Other materials		8.50		8.50
Total direct costs	47.77		34.87	
Indirect costs		3.75		3.75
Total, S	51.52		38.62	
Interest on working capital[c]		0.91		0.72
Manufacturing cost	52.43		39.43	

[a]Linear interpolation in Table 15.

[b]Assuming kiln size shown in footnote *a* of Table 21; $CaCO_3$ cost is $2.00/ton; total cost of CO_2 is 73.7¢/MSCF; in cases where by-product CO_2 is available, this can be omitted.

[c]Interest on working capital = $S/[(365E/60i) - 1]$; $E = 0.95$ for electrolysis and $E = 0.90$ for reforming.

Example 5. Determine the manufacturing cost of chlorine and caustic soda by brine electrolysis using power at 3 mills/kwhr and salt at $2.00 per ton. Assume a 1200-ton/day plant (Cl_2) and 10% cost of money.

Cost Component		Cost (Table 31, dollars per ton of chlorine)
Raw materials		3.70
Utilities		
Electricity		9.75
Cooling water		0.50
Steam		0.96
Labor and overhead		2.89
Other materials		5.90
Total direct costs	23.70	
Indirect costs		8.97
Total, S	32.67	
Interest on working capital[a]		0.58
Manufacturing cost[b]	33.25	

[a]Interest on working capital = $S/[(365E/60i) - 1]$; $E = 0.95$.
[b]This is the manufacturing cost per co-ton, 1 ton of chlorine plus 1.13 tons of caustic soda.

Example 6. Determine the total annual manufacturing costs for an industrial complex located in the United States which produces 655 tons/day of elemental phosphorus (P_4) (equivalent to 1500 tons/day of P_2O_5) and 685 tons/day of fabricated aluminum. Compare the total manufacturing costs for the complex with the total income from sales assuming that the cost of money is 10% using the data of examples 2 and 3 (plant A). Assume that power costs 4 mills/kwhr.

Cost Component	Elemental Phosphorus (dollars per ton of P_2O_5)		Fabricated Aluminum (dollars per ton of aluminum)	
Raw material		48.83		82.85
Utilities		21.75		85.78
Labor and overhead		5.34		120.58
Other materials		4.65		31.93
Total direct costs	80.57		321.14	
Capital investment (millions of dollars) (battery limits plants)		46.5		310.2
Off-site investment (millions of dollars)[a]		4.4		29.0
Total investment		50.9		339.2
Indirect costs		13.14[b]		178.36[c]
Total, S	93.71		499.50	
Interest on working capital[d]		1.69		8.99
Manufacturing cost	95.40		508.49	
Sales price[e]	100.00		650.00	

Annual profit from complex = $365 \times 0.93 \times 1500\ (100.00 - 95.40) + 365 \times 685\ (650.00 - 508.49)$
= \$37,723,243

[a]From Eq. (1), text; off-sites $= 0.931/(356.7)^{0.391} \times 356.7 = \$33.4$; $46.5/356.7 \times 33.4 = 4.4$.

[b]Capital recovery factor (for $i = 10\%$ and 15-year life) $= i(1+i)^n/(1+i)^n - 1 = 0.13147$; indirects $= 0.13147 \times 50{,}900{,}000/(1500 \times 365 \times 0.93) = \$13.14$ per ton of P_2O_5.

[c]Indirects $= 0.13147 \times 339{,}200{,}000/(685 \times 365) = \$178.36$ per ton of aluminum.

[d]Interest on working capital $= S/[(365E/60i) - 1]$; $E = 0.93$ for phosphorus and 1.00 for aluminum.

[e]From Table 10.

Example 7. Convert the manufacturing costs from the complex of example 6 to non-United States conditions. In this case bauxite is reduced from \$8.00 per ton to \$5.50 per ton[a] and phosphate rock is increased from \$9.60 to \$19.00 per ton.[b] The costs of other raw materials and utilities remain unchanged. Labor costs are halved, and the costs of supplies and other materials are increased by 10%. The capital costs of plants are separated into two components, an indigenously supplied component and an imported component, with the indigenous fraction tabulated for the various industrial plants.[c] The cost of the indigenous components of the plant are the same as United States costs, while the imported components are 20% higher than comparable equipment in the United States. For the phosphorus plant, 50% of the plant is imported equipment, whereas for aluminum, 20% of the extraction plant and 40% of the smelting and the fabricating plants are imported. Assume the same cost as example 6.

Correction of capital investment to non-United States conditions:

Phosphorus plant

Capital correction factor $= 1.20 \times 0.50 + 0.50 = 1.10$

Capital investment $= 1.10 \times \$46{,}500{,}000 = \$51{,}150{,}000$

Aluminum plant

Extraction plant: $1.20 \times 0.20 + 0.80 = 1.04$

Capital investment $= 1.04 \times \$65{,}700{,}000^{d} = \$68{,}328{,}000$

Smelting and fabrication plants: $1.20 \times 0.40 + 0.60 = 1.08$

Capital investment $= 1.08\,(134{,}400{,}000 + 110{,}100{,}000)^{d} = \$264{,}060{,}000$

Total aluminum plant investment (battery limits) = \$332,388,000

Off-site investment $= (51{,}150{,}000 + 332{,}388{,}000) \times 0.931/(51.5 + 332.388)^{0.391} = \$34{,}872{,}975$

Example 7 (continued)

	Phosphorus Plant	Aluminum Plant
Capital investment (B.L.), millions of dollars	51.2	332.4
Off-site investment, millions of dollars	4.6	30.3
Total investment	55.8	362.7

Cost Component	Elemental Phosphorus (dollars per ton of P_2O_5)		Fabricated Aluminum (dollars per ton of aluminum)	
Raw material		83.80		72.08
Utilities		21.75		85.78
Labor and overhead		2.67		60.29
Other materials		5.12		35.12
Total direct costs	113.34		253.27	
Indirect costs[e]		14.41		190.72
Total, S	127.75		443.99	
Interest on working capital[f]		2.30		7.42
Total manufacturing cost	130.05		451.41	
Sales price[g]	131.00		800.00	

Annual profit from complex (after servicing debt at 10%) = $365 \times 0.93 \times 1500\,(131.00 - 130.05) + 365 \times 685\,(800.00 - 451.41) = \$87{,}639{,}931$

[a]Indigenous raw material.
[b]Imported raw material.
[c]ORNL-4290, p. 20, Table 3.2.
[d]From Table 2.
[e]As in footnotes *b* and *c* of example 6.
[f]As in footnote *d* of example 6.
[g]From Table 10.