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PROCESS FEASIBILITY STUDY IN SUPPORT OF SILICON MATERIAL TASK I

Quarterly Technical Progress Report (XVII), September—November 1979

By
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December 1979

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Lamar University
Chemical Engineering Department
Beaumont, Texas

U.S. Department of Energy

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Reporting Period: Sept.-Nov., 1979

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ABSTRACT

Analyses were continued for process system properties of chemical materials important in the production of silicon. Primary activities were initiated for physical, transport and thermodynamic property data of silicon. Progress and status including preliminary data collection and analysis results are reported for the primary activities of data collection (90%), data analysis (80%), estimation (70%), and correlation (60%).

Process design results for BCL process-Case A (two deposition reactors and six electrolysis cells) were presented recently. During this reporting period, major chemical engineering efforts were initiated on preliminary process design of the BCL process-Case B (one deposition reactor and two electrolysis cells). Chemical engineering design results are reported for Case B including raw materials, utilities, major process equipment and production labor requirements for a silicon plant of 1,000 MT/yr capacity.

For economic analysis, major efforts centered on cost sensitivity analysis for the BCL process-Case A for producing silicon. Cost sensitivity results are presented for the influence of primary cost parameters. For both 1975 and 1980 time periods, the results indicate that the cost parameter influence on product cost is: plant investment (most), raw materials (intermediate), utilities (intermediate) and labor (least). For profitability, the results indicate a sales price of 14 $/kg (1980 dollars), at a 7.5% DCF rate of return on investment after taxes. These results suggest good potential of the BCL process for meeting the LSA cost goal of 14$ per kg (1980 dollars).

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I. PROCESS SYSTEM PROPERTIES ANALYSES (TASK 1)

Analyses were continued for process system properties of chemical materials important in the production of silicon. Primary activities were initiated for physical, thermodynamic, and transport property data of silicon.

The progress for the primary activities and status including preliminary data collection and data analysis results are summarized below:

	Prior	Current
1. Prel. Data Collection	0%	90%
2. Data Analysis	0%	80%
3. Estimation Methods	0%	70%
4. Exp. Corr. Activities	0%	60%
5. Property Values	0%	55%

The property data coverage for silicon will include critical constants, vapor pressure, heat of vaporization, heat capacity, density, surface tension, viscosity and thermal conductivity. Additional progress including preliminary data collection and data analysis results will be presented in the next report.

II. CHEMICAL ENGINEERING ANALYSIS (TASK 2)

A. BCL PROCESS - Case B

Major efforts were initiated on the preliminary process design for Case B of BCL process. In Case B, the process contains one deposition reactor and two electolysis cells as compared with two deposition reactors and six electolysis cells for Case A which was recently reported.

The detailed status for Case B is shown in Table IIA-1.0 to present the items that make up the preliminary process design.

The summarized results for the preliminary process design are presented in a tabular format to make it easier to locate times of specific interest. The guide for these tables is given below:

.Base Case Conditions.................Table IIA-1.1
.Reaction Chemistry...................Table IIA-1.2
.Raw Material Requirements............Table IIA-1.3
.Utility Requirements.................Table IIA-1.4
.Major Process Equipment..............Table IIA-1.5
.Production Labor Requirements........Table IIA-1.6

These results were forwarded for preliminary economic analysis.

TABLE IIA-1.0 CHEMICAL ENGINEERING ANALYSES: PRELIMINARY PROCESS DESIGN ACTIVITIES FOR BCL Process (Case B)

Prel. Process Design Activity	Status
1. Specify Base Case Conditions	●
1. Plant Size	●
2. Product Specifics	●
3. Additional Conditions	●
2. Define Reaction Chemistry	●
1. Reactants, Products	●
2. Equilibrium	●
3. Process Flow Diagram	●
1. Flow Sequence, Unit Operations	●
2. Process Conditions (T, P, etc.)	●
3. Environmental	●
4. Company Interaction (Technology Exchange)	●
4. Material Balance Calculations	●
1. Raw Materials	●
2. Products	●
3. By-Products	●
5. Energy Balance Calculations	●
1. Heating	●
2. Cooling	●
3. Additional	●
6. Property Data	●
1. Physical	●
2. Thermodynamic	●
3. Additional	●
7. Equipment Design Calculations	●
1. Storage Vessels	●
2. Unit Operations Equipment	●
3. Process Data (P, T, rate, etc.)	●
4. Additional	●
8. List of Major Process Equipment	●
1. Size	●
2. Type	●
3. Materials of Construction	●
8a. Major Technical Factors (Potential Problem Areas)	●
1. Materials Compatibility	●
2. Process Conditions Limitations	●
3. Additional	●
9. Production Labor Requirements	●
1. Process Technology	●
2. Production Volume	●
10. Forward for Economic Analysis	●

0 Plan
⊖ In Progress
● Complete

TABLE IIA-1.1

BASE CASE CONDITIONS FOR BCL PROCESS (Case B)

1. Plant Size
   - silicon produced from silicon tetrachloride (TET)
   - 1000 metric tons/yr of silicon
   - solar cell grade silicon
   - solid phase product form (granules)
2. Light End Distillation
   - purification of TET by distillation
   - remove 4% chlorosilanes as the light end
   - 80°C, 10 psig

3. Heavy End Distillation
   - purification of TET by distillation
   - remove 4% impurities as the heavy end
   - 92% over-all yield of TET from both distillations
   - 80°C, 10 psig

4. TET Vaporizer
   - to supply TET vapor for deposition reactor
   - by power input (resistance heater)
   - hold at constant level and constant pressure
   - 164°F

5. Deposition Reactor
   - reduce TET by zinc to produce silicon
   - deposit on pure silicon seed
   - fluid bed
   - 927°C (1700°F, 1 atm)
   - 63% conversion of TET to silicon

6. Reactor Condenser
   - to condense gases from reactor ($ZnCl_2$, unreacted Zn and $SiCl_4$ gases) partial condensation
   - using therminol 66 as the coolant
   - 927°C inlet temperature and 350°C outlet temperature

7. Reactor $ZnCl_2$ Stripper
   - work as partial condenser
   - to condense $ZnCl_2$ gas from $SiCl_4$ gas
   - operating at the temperature right above $ZnCl_2$ melting point (318°C), 350°C
   - using therminol 66 as the coolant

8. Cell $ZnCl_2$ Stripper
   - operates as partial condenser
   - to condense $ZnCl_2$ gas from Cl_2 and $SiCl_4$ gases
   - operating at the temperature right above $ZnCl_2$ melting point (318°C), 350°C
   - using therminol 66 as the heat exchange medium

TABLE IIA-1.1 (Continued)

9. Reactor $SiCl_4$ Condenser
   - condense $SiCl_4$ gas for recycle
   - antifreeze as the coolant
   - 350°C inlet temperature, 20°F outlet temperature.

10. Electrolysis
   - electrolytic recovery of Zn from $ZnCl_2$
   - Cl_2 gas is by product
   - 95% Zn recovery
   - 500°C, approx. 1 atm

11. Zinc Vaporizer
   - to vaporize Zinc
   - by induction heating
   - 927°C, approx. 1 atm.

12. Wastes Treatment
   - to scrub and neutralize $SiCl_4$ and chlorosilane gases
   - caustic solution used to neutralize

13. Operating Ratio
   - approximately 80% utilization (on stream time)
   - approximately 7,000 hr/yr production

14. Storage Considerations
   - feed material (two week supply)
   - product (two shifts storage)
   - process (several hours)

TABLE IIA-1.2
REACTION CHEMISTRY FOR BCL PROCESS (Case B)

1. <u>Silicon Deposition</u>

   $2Zn + SiCl_4 \rightarrow Si\downarrow + 2ZnCl_2$

2. <u>Electrolysis</u>

   $ZnCl_2 \xrightarrow{electroly.} Zn(l) + Cl_2\ (g)$

3. <u>Waste Treatment</u>

   $SiCl_4 + 2H_2O \xrightarrow{aq} SiO_2 + 4HCl(aq)$

   $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O$

   or

   $Ca(OH)_2(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + 2H_2O$

3a. <u>Waste Treatment (50 MT/yr unit)</u>

   $Cl_2(g) + 2NaOH(aq) \rightarrow NaOCl(aq) + NaCl(aq) + H_2O$

Table IIA-1.3

Raw Material Requirements for
BCL Process (Case B)

Raw Material	Requirements lb/KG of Silicon
1. Silicon Tetrachloride, $SiCl_4$	15.33
2. Zinc, Zn	0.54
3. Caustic (50%), NaOH(aq)	3.75
or	
Lime (99%), $Ca(OH)_2$	1.75
4. Argon	3.1 SCF*
5. Nitrogen	7.6 SCF*
6. Chlorine, Cl_2 (by-product)	11.12

*Estimate from BCL

TABLE IIA-1.4 UTILITY REQUIREMENTS FOR BCL PROCESS (Case B)

Utility/Function		Requirements/Kg of Silicon Product
1. Electricity		29.40 Kw-hr
1. Low Voltage D.C. for Electrolysis	(20.51)	
2. Zinc Vaporizer Induction Heated	(4.37)	
3. Preheat Section of Deposition Unit Induction Heated	(1.12)	
4. Electrolysis Feed Tank Heater	(0.24)	
5. Molten Zinc Storage Heater	(0.10)	
6. $SiCl_4$ Vaporizer	(0.53)	
7. Pumps, Blowers	(2.53)	
2. Steam (50 PSIA)		9.67 pounds
1. #1 Purification Column Calandria	(4.59)	
2. #2 Purification Column Calandria	(4.30)	
3. Caustic Storage Heating	(0.29)	
4. #1 Purification Column Preheater	(0.49)	
3. Cooling Water		34.49 Gallons
1. #1 Purification Column Condenser	(16.94)	
2. #2 Purification Column Condenser	(15.88)	
3. Purified Tet Cooler	(1.67)	
4. Process Water		10.48 Gallons
1. Diluent for Waste Treatment	(10.48)	
5. Refrigeration		2.38 MBtu
1. Reactor $SiCl_4$ Condenser (H-11)	(1.28)	
2. $SiCl_4$ Vent Condenser (H-07)	(1.10)	

TABLE IIA-1.5

LIST OF MAJOR PROCESS EQUIPMENT
FOR BCL (Case B)

Equipment	Function	Size/Type	Material of Construction	Capacity Ratio to 1000 MT/yr
PROCESS TOWER AND INTERNALS				
1. D-01 Light End Distillation Column	To purify $SiCl_4$	8" dia. x 21', packed 13.5'	Column, CS/packing, SS	20
2. D-02 Heavy End Distillation Column	To purify $SiCl_4$	8" dia. x 21', packed 13.5'	Column, CS/packing, SS	20
3. A-01 Primary $SiCl_4$ Vent Scrubber	To scrub $SiCl_4$ vent gas	3' dia. x 4'4" T/T, 225 gal/flat bottom	FRP	1
4. A-02 Final $SiCl_4$ Vent Scrubber	To scrub $SiCl_4$ vent gas	7'6" dia. x 17'4" T/T/ 4 pp trays, Teflon dimister	FRP	1
HEAT EXCHANGER				
5. H-01 L.E. Column Feed Heater	To preheat feed to D-01	2' dia. x 5', 15,013 Btu/hr / external heater	CS	20
6. H-02 L.E. Column Reboiler	Reboiler of D-01	2' dia. x 3', 51,522 Btu/hr / external heater	CS	20
7. H-03 L.E. Column Condenser	Total condenser of D-01	47,430 Btu/hr/shell-tube H.E.	CS	20
8. H-04 H.E. Column Feed Heater	To preheat feed to D-02	2' dia. x 5', 14,331 Btu/hr/external heater	CS	20

TABLE IIA-1.5 (Continued)

9.	H-05 H.E. Column Reboiler	Reboiler of D-02	2' dia. x 3', 56,641 Btu/hr/external heater	CS	20
10.	H-06 H.E. Column Condenser	Total condenser of D-02	52,292 Btu/hr/shell-tube H.E.	CS	20
11.	H-07 $SiCl_4$ Vent Condenser	Condense $SiCl_4$ from vent gas	38 ft^2, 18,000 Btu/hr/shell-tube H.E.	CS	20
12.	H-08 $SiCl_4$ Vaporizer	To provide $SiCl_4$ vapor to reactor	2.75' dia. x 3' T/T, 13,648 Btu/hr/resistance heater	CS	40
13.	H-09 Reactor Condenser	To condense by products from reactor	14" dia. x 6.4', 126,237.2 Btu/hr	Graphite W/SS shell	40
14.	H-10 Reactor $ZnCl_2$ Stripper	To condense $ZnCl_2$ gas	12 ft^2, 2,652 Btu/hr/shell-tube H.E., finned U-tube	316 SS	20
15.	H-11 $SiCl_4$ Condenser	To condense $SiCl_4$ gas for recycle	6,401 Btu/hr (x 4.62 = 29.573 Btu/hr)	316 SS	20
16.	H-12 Cell $ZnCl_2$ Stripper	To condense $ZnCl_2$ vapor	9,841.4 Btu/hr/shell-tube, H.E. (x 0.32)	Inconel 600	20
17.	H-13 Therminol Cooler (cold circuit)	To cool Therminol 66	68 ft^2, 11,000 Btu/hr/shell-tube H.E., 500 psia	CS	20
18.	H-14 Therminol Cooler (hot circuit)	To cool Therminol 66	262 ft^2, 120,000 Btu/hr/shell-tube H.E., 500 psia	CS	20
19.	H-15 Start-up Heater	Therminol start-up heater	98,950 Btu/hr/U-tube 15', resistance heater	CS	20
20.	H-16 Silicon Product Cooler (two)	To cool the Si product from reactor	5,735 Btu/hr	SiC	40

TABLE IIA-1.5 (Continued)

20a.	H-17 Chlorination Cooler		20,000 Btu/hr, Area 200 ft^2	SS	1
20b.	H-18 Cell Gas Cooler		1.08×10^5 Btu/hr, Area 1805 ft^2	CS	1
PROCESS AND STORAGE VESSELS					
21.	T-01 $SiCl_4$ Storage Tank	Storage/feed to purification	7' dia. x 16' T/T/ 4,600 gal	CS	20
22.	T-02 $SiCl_4$ Emergency Storage Tank	Storage/feed to purification	7' dia. x 16' T/T/ 4,600 gal	CS	20
23.	T-03 L.E. Column Reflux Drum	To hold distillate for reflux	12" dia. x 4'/23 gal	CS	20
24.	T-04 Surge Tank	Surge Tank for D-01 bottom	3' dia. x 4'/200 gal	CS	20
25.	T-05 Sump Tank	Sump for purification unit	3' dia. x 4'/200 gal	CS	20
26.	T-06 H.E. Column Reflux Drum	To hold distillate for reflux	12" dia. x 4'/23 gal	CS	20
27.	T-07 Pure $SiCl_4$ Storage Tank	Storage/feed to $SiCl_4$ Vaporizer	6' dia. x 10' T/T/ 1900 gal	CS	20
28.	T-08 Electrolysis Feed Tank	Storage/feed $ZnCl_2$ to electrolysis cell	50" x 158" x 38"H/ 7" graphite TH	Graphite/304 SS	20
29.	T-09 Molten Zinc Storage Tank	Storage/feed to Zinc vaporizer	W/heater 68,242 Btu/hr	Graphite/304 SS	20
30.	T-10 Therminol Head Tank	Storage Therminol	1.5' dia. x 3.75' T/T/ 49.6 gal	CS	20

31.	T-11 Therminol Drain Down Tank	To store drained Therminol	2.75' dia. x 3' T/T/ 133 gal	CS	20
32.	T-12 Chlorine Supply Tank	To supply chlorine gas	1 1/2' dia. x 3'/ 37.62 gal	CS	20
33.	T-13 Lime Storage Tank	Storage Lime	12' dia. x 14'6" T/T/ 12,000 gal	FRP	1

PUMPS WITH DRIVERS

34.	P-01 Purification Feed Pump	To feed $SiCl_4$ to storage tank	30 gpm, 31' head/ centrifugal, 1 1/2 hp	CS	20
35.	P-02 L.E. Column Feed Pump	To supply $SiCl_4$ to preheater	28.9 gph, Δp = 72 psia/ 0.5 hp.	CS	20
36.	P-03 L.E. Column Relux Pump	D-01 Reflux	51.7 gph, Δp = 23 psia/ 0.5 hp.	CS	20
37.	P-04 Surge Tank Pump	To supply $SiCl_4$ to H.E. Column	29.4 gph, Δp = 53 psia/ 0.5 hp.	CS	20
38.	P-05 Sump Pump	To pump $Sicl_4$ to emergency tank	30 gpm, 31' head/ centrifugal, 1 1/2 hp.	CS	20
39.	P-06 L.E. Column Bottom Pump	To pump $SiCl_4$ to surge tank	29.4 gph, Δp = 53 psia/ 0.5 hp.	CS	20
40.	P-07 H.E. Column Relux Pump	D-02 Reflux	57.1 gph, Δp = 25 psia/ 0.5 hp.	CS	20
41.	P-08 H.E. Column Bottom Pump	To pump bottom solution to waste treatment	1.3 gph, Δp = 25 psia/ 0.5 hp.	CS	20
42.	P-09 $SiCl_4$ Vaporizer Feed Pump	To feed $SiCl_4$ to Vaporizer	15 gph, 31' head/ 1/2 hp	CS	20

TABLE IIA-1.5 (Continued)

43.	P-10 Reactor Condenser Circulating Pump	To circulate condensates	2.4 gpm, 30' head/1/2 hp	Graphite	40
44.	P-11 Cold Circuit Pump (two)	Cold Therminol circulation	20 gpm, 85' head/centrifugal, 2 hp.	CS	20
45.	P-12 Hot Circuit Pump	Hot Therminol circulation	62 gpm, 85' head/centrifugal, 4 hp.	CS	20
46.	P-13 Primary Scrubber Recirculation Pump	Recirculation for Scrubber A-01	20 gpm, 125' head/centrigugal, 2.5 hp.	Duriron	1
47.	P-14 Primary Scrubber Lower-loop Recirculating Pump	Circulate solution for Lower-loop of Scrubber A-02	100 gpm, 103' head/centrifugal, 7 1/2 hp.	Duriron	1
48.	P-15 Primary Scrubber Upper-loop Recirculating Pump	Circulate solution for upper-loop of Scrubber A-02	100 gpm, 13' head/centrifugal, 2 hp.	Duriron	1
49.	P-16 Make up Lime Metering Pump	Lime make up	0.9 gpm, 25' head/centrifugal, 1/2 hp.	CS	1

FILTERS

50.	F-01 L.E. Column Feed Filter	Remove solids	29 gph, Δp = 5 psia/140 micron	CS	20
51.	F-02 L.E. Column Reflux Filter	Remove solids	30 gph, Δp = 5 psia/140 micron	CS	20
52.	F-03 H. E. Column Feed Filter	Remove solids	52 gph, Δp = 5 psia/140 micron	CS	20
53.	F-04 H.E. Column Relfux Filter	Remove solids	31 gph, Δp = 5 psia/140 micron	CS	20

TABLE IIA-1.5 (Continued)

54.	F-05 Therminol Cooler Blower Filter	To filter the solids from air			20

SPECIALIZED EQUIPMENTS

55.	R-01 Fluidized Bed Reactor (two)	To reduce $SiCl_4$ to Si by Zn	1830.2 Btu/hr, 6.5" dia.	Graphite Lined / SS	40
56.	FN-01 Furnace (two)	To preheat $SiCl_4$ gas	272,966 Btu/hr		40
57.	B-01 Seed Addition Hopper (two)	To feed Si seed to the reactor		310 SS	40
58.	B-02 Si Product Hopper (four)	To hold Si product	6 gal	310 SS	20
59.	B-03 Zinc Hopper	To hold make up Zinc	40 gal	CS	20
60.	C-01 Therminol Cooler Blower	Therminol system air cooler blower	500 acfm fan/electric, 1 1/2 hp., 12-1/2" wheel	CS	20
61.	C-02 Scrubber Vent Blower	Suck $SiCl_4$ gas for A-01 & A-02	10,000 acfm/electric, 50 hp. 31-1/2" wheel	FRP	1
62.	E-01 Eductor (two)	$SiCl_4$ scrubbing (Scrubber D-05)	20 gpm, Δp = 47.4 psia/ Hydraulic ejector, 1-1/2" NPT	P.V.C.	1
63.	EC-01 Electrolysis Cell (six)	To recover Zn from $ZnCl_2$	5,000 ~6,000 amp cells	Graphite/SS	60
64.	PW-01 Power Supply	To supply power to electrolysis cell	545,933 Btu/hr.		20
65.	VP-01 Zinc Vaporizer (two)	To provide zinc vapor to reactor	104,128.8 Btu/hr 13.5" dia. x 32"	Quartz	40

TABLE IIA-1.5 (Continued)

NOTE:

1. For the 1000 MT/yr plant, items 3, 4, 33, 46, 47, 48, 49, 61, and 62 are used for waste treatment of distillation wastes (light, heavy) and vent gases.

2. In the 50 MT/yr facility, these items are used for hypochlorite maufacture which is not present in the 1000 MT/yr plant.

3. For H-11, the operation conditions were changed from 171°F ~ 32°F to 662°F ~ 20°F.

4. For H-12, the operations conditions have been chnaged from ΔT = 855°F to 270°F.

TABLE IIA-1.6

PRODUCTION LABOR REQUIREMENTS FOR BCL PROCESS (Case B)

Section		Labor man-hr/KG Si (oper/shift)
1. Purification	(I)	0.01402 (2)
2. Deposition	(II)	0.01402 (2)
3. Electrolysis	(III)	0.02103 (3)
4. Waste Treatment	(IV)	0.00701 (1)
5. Product Handling	(V)	0.00701 (1)
	TOTAL	0.06309 (9)

Note

Manpower estimate for production labor requirements based on:

1. Dividing plant into sections
   - -type of unit operation
   - -mark off working area

2. Specify work duties required in each section

3. Estimate operators required to perform work duties in each section
   - -type of unit operation
   - -size of working area
   - -degree of automation (batch, semi-continuous, continuous, etc.)

B. OTHER PROCESSES

Other processes (such as SRI process, UCC silane process, Hemlock Semiconductor process, etc.) under consideration for solar cell grade silicon production are being monitored with respect to data relative to chemical engineering analysis.

III. ECONOMIC ANALYSIS (TASK 3)

During this reporting period, economic analysis was continued for the BCL process - Case A for producing silicon. Case A is based on two deposition reactors (approx. 2 ft. dia.) and six electrolysis cells. Major efforts centered on cost sensitivity analysis of the process including the influence of raw materials, labor, utilities and capital investment.

The status and progress achieved since the last reporting period are summarized below for the subitems making up the cost sensitivity analysis:

		Prior	Current
1.	Base Case Conditions	40%	100%
2.	Return on Orig. Invest.	40%	100%
3.	Discounted Cash Flow Rate of Return	40%	100%
4.	Plant Invest. Cost Var.	40%	100%
5.	Raw Material Cost Var.	40%	100%
6.	Utilities Cost Var.	40%	100%
7.	Labor Cost Var.	40%	100%
8.	Effect of Inflation	40%	100%
9.	Cost and Profitability Analysis Summary	40%	100%

A detailed status sheet showing that these activities are completed is presented in Table III-1.0.

The preliminary cost sensitivity analysis is being performed to determine the influence of cost parameters on the economics of producing silicon by this new technology. The cost sensitivity results for the 1975 time period are given in Figure III-1.1 in which product cost ($/kg Si) is plotted versus variation (-100% to 0% to +100%) of the primary cost parameters (plant investment, raw materials, labor and utilities). The 0% variation represents the base case. The -100% variation corresponds to the case of no costs for the parameters; and the +100% represents the case for the doubling of cost for each parameter. The plot illustrates that product cost is influenced most by plant investment and least by utilities.

The cost sensitivity results for the 1980 time period are presented in Figure III-1.2 for the primary cost parameters. The results indicate that the cost parameter influence on product cost is: plant investment (most), raw materials (intermediate), utilites (intermediate) and labor (least).

The product cost represents all cost associated with producing one kilogram of silicon. On top of these costs a producing company will include some profit. The sales price of the product silicon will actually be the sum of the product cost and a profit for the company. The profit is usually measured in terms of rate of return on the capital investment that the company spent in going into the polysilcion business. Two profitabiltiy methods which are commonly used are the retun on original investment (%ROI) and discounted cash flow rate of return (%DCF).

The cost and profitability analysis summary for this process are presented in Table III-1.3 for both 1975 and 1980 time periods. The sales price of polysilicon at various rates or return for both profitability mehtods (%ROI and %DCF) is shown in the lower half of the table. The results indicate a sales price of 10 $/kg of silicon (1975 dollars), or 14 $/kg (1980 dollars), at a 7.5 %DCF rate of return after taxes for the process. This means that this process has good potential to meet the LSA cost goal for 10% per kg (1975 dollars) or 14$ per kg (1980 dollars).

The effect of inflation (higher costs for raw material, utilities, labor, etc.) is shown in Figure III-1.4. For the figure, product cost is plotted against time at various inflation levels (0%, 5%, 7%, and 10% inflation) for the 1975-1990 time period.

TABLE III-1.0

COST SENSITIVITY ANALYSIS:
PRELIMINARY COST SENSITIVITY ACTIVITIES FOR BCL PROCESS (Case A)

Prel. Sensitivity Activity	Status
1. Specify Base Case Conditions	●
1. Process	●
2. Plant Size	●
3. Product	●
4. Cost Data	●
2. Return on Original Investment	●
1. Capital Investment	●
2. Taxes	●
3. % ROI	●
3. Discounted Cash Flow Rate of Return	●
1. Capital Investment	●
2. Taxes	●
3. % DCF	●
4. Plant Investment Cost Variation	●
1. Major Process Equipment	●
2. Installation, Piping	●
3. Instrumentation, Buildings	●
4. Offsites	●
5. Indirects, Engineering	●
6. Fixed, Working Capital	●
7. Other	●
5. Raw Material Cost Variation	●
1. Major Raw Materials	●
2. Waste Treatment	●
3. By-Product	●

Prel. Sensitivity Analysis	Status
6. Utilities Cost Variation	●
1. Steam	●
2. Electricity	●
3. Cooling Water	●
4. Process Water	●
5. Other	●
7. Labor Cost Variation	●
1. Production Labor	●
2. Labor Rate	●
3. Staffing Estimate	●
8. Effect of Inflation	●
1. Rate	●
2. Future	●
9. Cost and Profitability Analysis Summary	●
1. Plant Investment	●
2. Product Cost	●
3. Sales Price (Profit)	●

0 Plan
◐ In Progress
● Complete

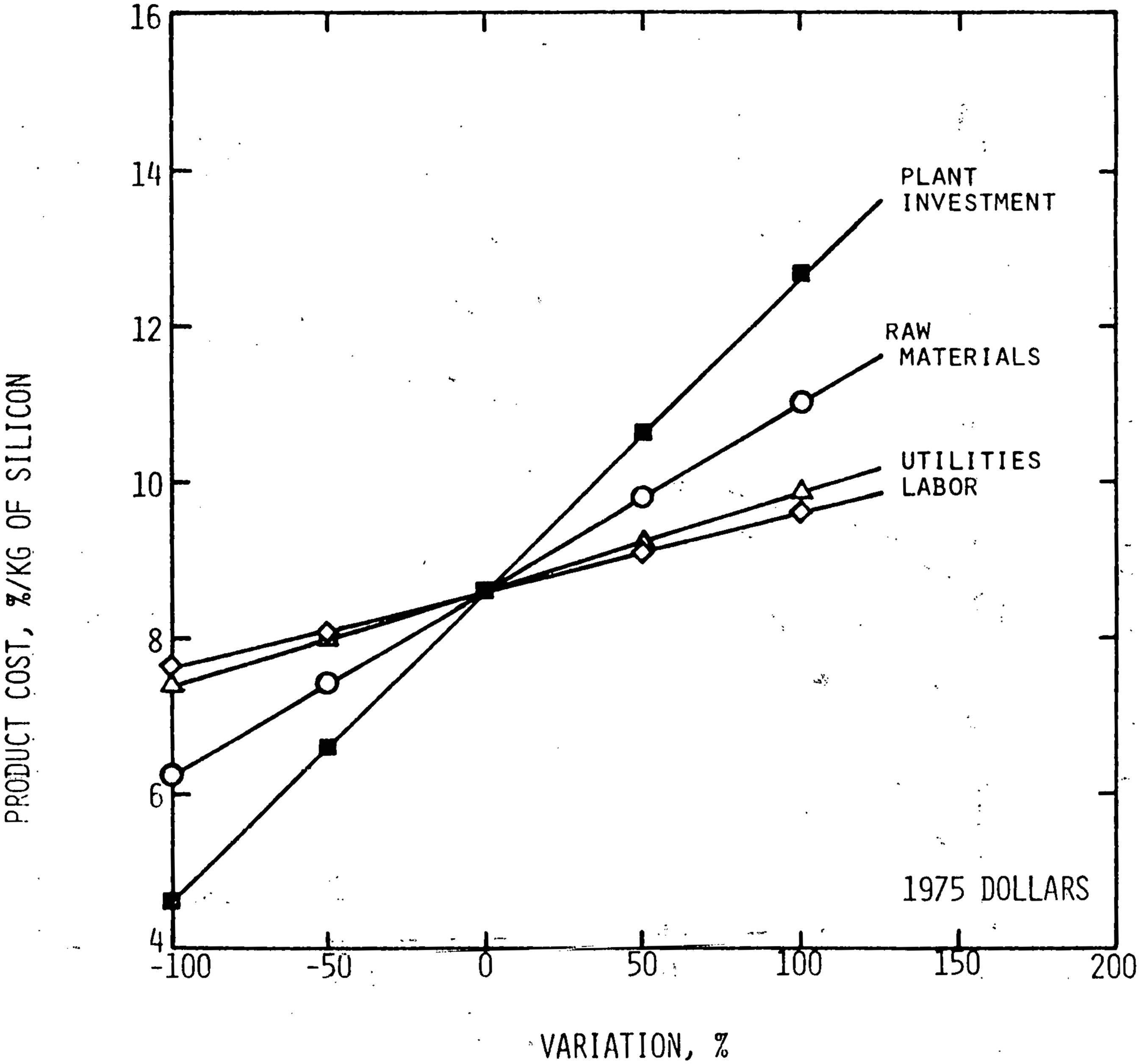


Figure III-1.1 COST SENSITIVITY ANALYSIS OF BCL PROCESS

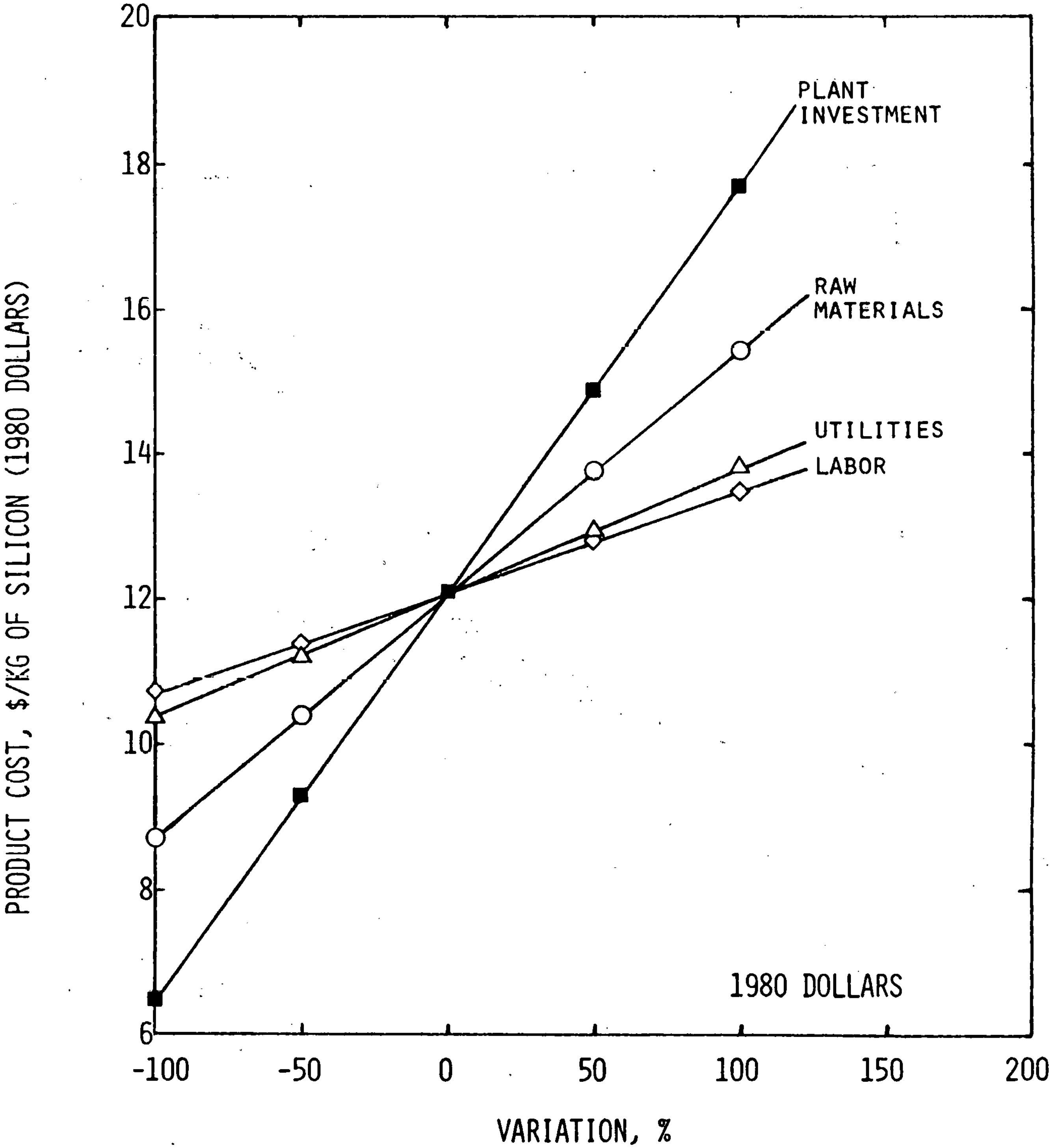


Figure III-1.2 COST SENSITIVITY ANALYSIS OF BCL PROCESS

TABLE III-1.3

COST AND PROFITABILITY ANALYSIS SUMMARY FOR BCL PROCESS

1. Process.......................................BCL Process
2. Plant Size....................................1,000 Metric Tons/year
3. Plant Product.................................Silicon
4. Product Form..................................Silicon Granules
5. Plant Investment..............................$14,340,000/$20,070,000 (1975 dollars) (1980 dollars)

		(1975 dollars)	(1980 dollars)
Fixed Capital		$12.47 Mega	$17.45 Mega
Working Capital (15%)		1.87 Mega	2.62 Mega
	TOTAL	$14.34 Mega	$20.07 Mega

6. Product Cost..................................8.63 $/Kg (1975 dollars)
7. Tax Rate (Federal)............................46%
8. Return on Original Investment, after taxes (%ROI)

	Sales Price $/Kg of Silicon (1975 dollars)	Sales Price $/Kg of Silicon (1980 dollars)
0% ROI..............	8.63	12.08
5% ROI..............	9.96	13.94
10% ROI..............	11.28	15.80
15% ROI..............	12.61	17.65
20% ROI..............	13.94	19.51
25% ROI..............	15.27	21.37
30% ROI..............	16.59	23.23
40% ROI..............	19.25	26.95

9. Discounted Cash Flow Rate of Return, after taxes (%DCF)

	Sales Price $/Kg of Silicon (1975 dollars)	Sales Price $/Kg of Silicon (1980 dollars)
0% DCF..............	8.63	12.08
5% DCF..............	9.48	13.28
10% DCF..............	10.42	14.59
15% DCF..............	11.44	16.01
20% DCF..............	12.52	17.53
25% DCF..............	13.65	19.11
30% DCF..............	14.83	20.76
40% DCF..............	17.27	24.18

Based on 10 year project life and 10 year straight line depreciation.

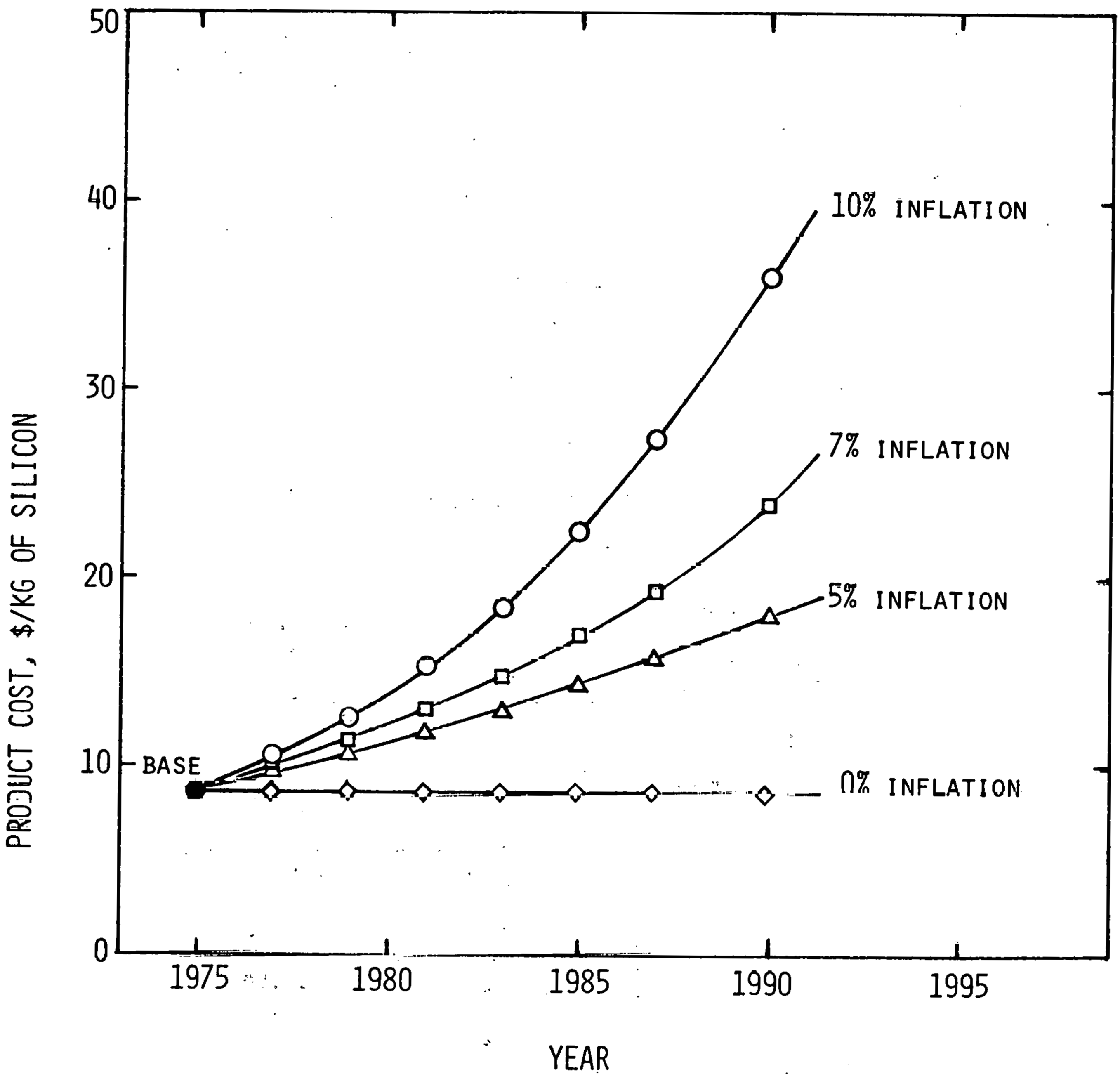


Figure III-1.4 INFLATION EFFECT

IV. SUMMARY - CONCLUSIONS

Based on achievements during this reporting period, the following summary-conclusions are made:

1. Task 1

Process system properties analyses were continued for chemical materials important in the production of silicon. Major activities were initiated for physical, transport and thermodynamic property data for silicon. Status and progress are reported for data collection (90%), data analysis (80%), estimation (70%) and correlation (60%).

2. Task 2

Process design results for BCL process - Case A (two deposition reactors and six electrolysis cells) were presented during the last reporting period. During this reporting period, major chemical engineering efforts were initiated on preliminary process design of the BCL process - Case B (one deposition reactor and two electrolysis cells). Chemical engineering design results are reported for Case B including raw materials, utilities, major process equipment and production labor requirements for a silicon plant of 1,000 MT/yr capacity.

3. Task 3

For economic analysis, major efforts centered on cost sensitivity analysis of the BCL process - Case A for producing silicon. Cost sensitivity results are presented for the influence of primary cost parameters. For both 1975 and 1980 time periods, the results indicate that the cost parameter influence on product cost is: plant investment (most), raw materials (intermediate), utilities (intermediate) and labor (least). For profitability, the results indicate a sales price of 14 $/kg (1980 dollars), at a 7.5 %DCF rate of return on investment after taxes. These results suggest good potential of the BCL process for meeting the LSA cost goal of 14$ per kg (1980 dollars).

V. PLANS

Plans for the next reporting period are summarized below:

1. Task 1

Continue analysis of process system properties for chemical materials important to the production of silicon.

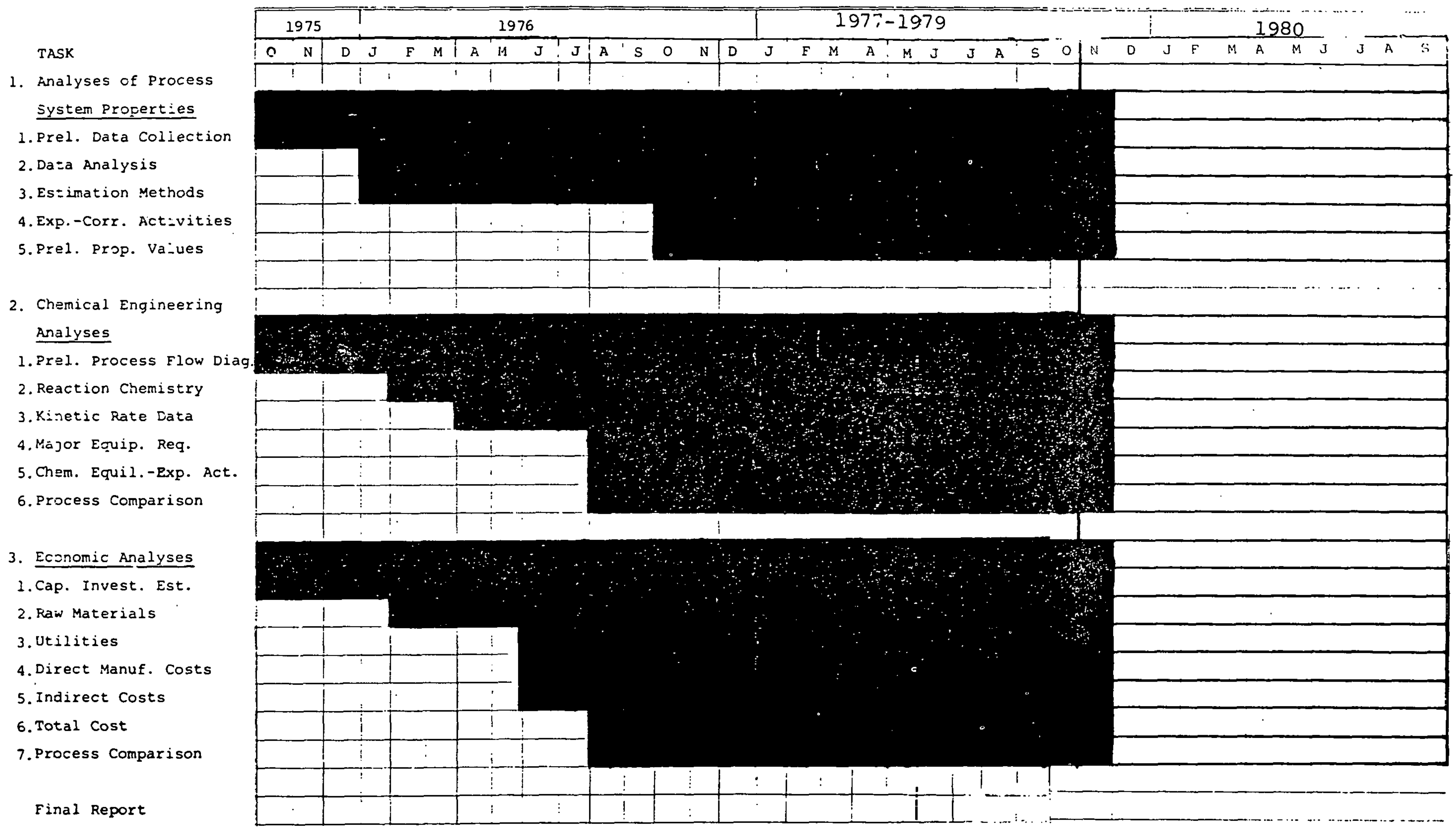
2. Task 2

Continue chemical engineering analysis of processes under consideration for producing silicon.

3. Task 3

Perform economic analysis of processes as results issue from chemical engineering analysis.

MILESTONE CHART



PROCESS FEASIBILITY STUDY IN SUPPORT OF SILICON MATERIAL TASK I

JPL Contract No. 954343

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