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NIOSH / OSHA

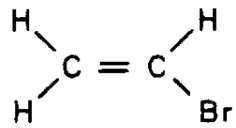
Current Intelligence Bulletin 28

September 21, 1978

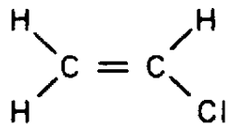
VINYL HALIDES

CARCINOGENICITY

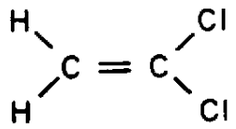
Vinyl Bromide



Vinyl Chloride



Vinylidene Chloride



U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

U. S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration

JOINT NIOSH/OSHA

CURRENT INTELLIGENCE BULLETIN: VINYL HALIDES - CARCINOGENICITY

Vinyl Bromide, Vinyl Chloride, and Vinylidene Chloride

September 21, 1978

The National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) jointly recommend that vinyl bromide and vinylidene chloride be considered in the workplace as potential carcinogens to humans and controlled with the same degree of prudence as vinyl chloride, another vinyl halide currently regulated as a carcinogen by OSHA. This recommendation is based on the results of recent studies indicating that exposure to vinyl bromide and to vinylidene chloride causes angiosarcoma of the liver and other cancers in laboratory animals. Safe levels of exposure to carcinogens have not been demonstrated, but lowered exposure to carcinogens may in general decrease the probability of cancer development.

Vinyl chloride is known to cause angiosarcoma of the liver and cancers of other sites in laboratory animals and in humans. At this time, adequate carcinogenicity studies of vinyl bromide and vinylidene chloride have been conducted only in laboratory animals. In view of the present state of knowledge in carcinogenesis, substances that cause cancer in laboratory animals are considered a potential cancer risk to humans.

Vinyl chloride is the only vinyl halide for which an OSHA exposure standard currently exists. In light of the recent laboratory animal studies demonstrating carcinogenicity of vinyl bromide and vinylidene chloride, NIOSH and OSHA have jointly prepared this Current Intelligence Bulletin. Its purpose is to advise the occupational health community of the pertinent data and implications for exposed workers. NIOSH and OSHA request that producers, distributors, professional associations, and unions transmit the information in this Bulletin to their customers, employees, associates, and members.

LABORATORY STUDIES

Carcinogenicity

Laboratory studies have demonstrated that exposure by inhalation to vinyl chloride (1,2), vinyl bromide (3), and vinylidene chloride (1,4) all caused angiosarcoma of

Mutagenicity

Several investigators have reported that vinyl chloride is mutagenic in Salmonella typhimurium and pombe (6-11) and in Escherichia coli (12-14). Vinyl chloride also has been shown to be mutagenic in the yeast mutation assay (11), in the Drosophila recessive lethal test (15,16), and in the host-mediated assay (11). Studies also have shown vinyl chloride to be mutagenic in Tradescantia (17). Three reports bearing on the mutagenicity of vinyl bromide have been noted to date. Bartsch et al., (18) and Simmons (19) have independently reported that vinyl bromide induced mutations in the bacterium, Salmonella typhimurium. In addition, Sparrow (17) has demonstrated a significant increase in mutants in Tradescantia exposed to vinyl bromide vapors. Vinylidene chloride has been shown to induce mutations in Salmonella typhimurium (10, 20-22), in Escherichia coli (12), and in Tradescantia (17).

Other Adverse Effects

Other adverse health effects in animals attributed to exposure to vinyl halides include central nervous system (CNS) effects, cardiovascular effects, respiratory effects, skin effects, skeletal effects, and liver or spleen abnormalities (1).

HUMAN STUDIES

Carcinogenicity

Studies of workers exposed to vinyl chloride have demonstrated an excessive risk of death from cancer of the lung, brain, lymphatic system, and angiosarcoma of the liver (1, 23). Cancers of the same sites were previously induced in animals following exposure to vinyl chloride (2).

Liver angiosarcoma in humans is a very rare malignant tumor of the blood vessels. Though no clinical signs or symptoms, or laboratory examinations have been found to be specific for the early diagnosis of this cancer, affected individuals may complain of fatigue, abdominal pain, weight loss, anorexia, nausea, vomiting, melena, indigestion, jaundice, hematemesis, or diarrhea. Other manifestations may include liver enlargement and liver function abnormalities. In adults, untreated angiosarcoma of the liver usually is fatal within 8 months. Even with treatment, death usually occurs within 16 months.

To date there have been no reported cases of cancer in humans associated with exposure to vinyl bromide or vinylidene chloride. However, vinyl bromide has been in commercial production in the U.S. only since 1971. Due to the long latent period characteristic of occupationally-induced cancers, typically 15-40 years, no unusual risk of cancer among exposed workers would be expected to be be detected at this time. Vinylidene chloride has been in commercial production and use since the early 1940's. The only study (24) reported to date showed no excessive cancer risk among workers occupationally exposed to vinylidene chloride, but methodologic limitations of this study do not permit an adequate evaluation of the carcinogenic risk of vinylidene chloride to humans.

Mutagenicity and Reproductive Effects

Cytogenetic studies have demonstrated a significant increase in the frequency of chromosomal aberrations in the lymphocytes of workers exposed to vinyl chloride (25-31). Further evidence for the mutagenicity of vinyl chloride has been provided by investigations showing an increase in fetal wastage among wives of male workers following occupational exposure to vinyl chloride (32,33). No studies addressing mutagenic or reproductive hazards among vinyl bromide or vinylidene chloride exposed populations have been reported.

Other Adverse Effects

Numerous other adverse health effects have been observed in humans exposed to vinyl chloride, as detailed in Table 2. Reports of effects on workers exposed to vinylidene chloride in combination with other vinyl compounds include liver function abnormalities, headache, vision problems, dizziness, fatigue, weakness, and neurological sensory disturbances. No similar reports for vinyl bromide exposure were found (1).

Table 2. Other Adverse Effects of Vinyl Chloride on Humans (1).

System	Adverse Effect
neurologic	dizziness, lightheadedness, dulling vision and hearing, drowsiness, headache, loss of memory, euphoria, nervousness, numbness or tingling in fingers or toes
gastrointestinal	nausea, loss of appetite, abdominal distress, varices of esophagus or stomach, black stools, bloody vomitus
cardiovascular	increased blood pressure, Raynaud's Syndrome
hepatic	liver enlargement, liver function abnormalities, increased sulphbromophthalein retention, liver damage, serum enzyme abnormalities
respiratory	coughing and sneezing, bronchial rales, emphyzema, pulmonary fibrosis, decreased respiratory function, lung function disturbances
hematologic	anemia, reticulocytosis, leukopenia, thrombocytopenia, splenomegaly
dermatologic	contact dermatitis, scleroderma-like skin changes
musculoskeletal	calf and joint pain, acroosteolysis
other	increased perspiration, cold sensation in fingers and hands, fatigue, weight loss, weakness, impotency

REFERENCES

1. U.S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. Criteria for a Recommended Standard....Occupational Exposure to Vinyl Halides. (To be published late 1978 - Transmitted to OSHA September 12, 1978).

2. Maltoni, C: Predictive Value of Carcinogenesis Bioassays. N.Y. Acad. Sci. 271:431-447 (1976).

3. Huntingdon Research Center, HRC Project 7511-253. 18-Month Sacrifice Pathology Report, (Vinyl Bromide). New York. (June 26, 1978).

4. Maltoni, C: Recent Findings on the Carcinogenicity of Chlorinated Olefins. Env. Health Perspect. 21:1-5 (1977b).

5. Maltoni, C: Vinyl Chloride Carcinogenicity: An Experimental Model for Carcinogenesis Studies. In: Origins of Human Cancer, H.H. Hiatt, J.D. Watson, and J.A. Winston, eds., Cold Spring Harbor, 4:119-146 (1977a).

6. Bartsch, H., C. Malaveille, R. Montesano: Human, Rat and Mouse Liver-Mediated Mutagenicity of Vinyl Chloride in S. Typhimurium Strains. Int. J. Cancer 15:429-437 (1975).

7. Rannug, U., A. Johansson, C. Ramel, and C.A. Wachtmeister: The Mutagenicity of Vinyl Chloride After Metabolic Activation. Ambio. 3:194-197 (1974).

8. Garro, A.J., J.B. Guttenpaln, and P. Milvy: Vinyl Chloride Dependent Mutagenesis: Effects of Liver Extracts and Free Radicals. Mutat. Res. 38 (2):81-88 (1976).

9. Andrews, A.W., E.S. Zawistowski, and C.R. Valentine: A Comparison of the Mutagenic Properties of Vinyl Chloride and Methyl Chloride. Mutat. Res. 40:273 (1976).

10. McCann, J., E. Choi, E. Yamasake, and B.N. Ames: Detection of Carcinogens as Mutagens in the Salmonella/Microsome Test: Assay of 300 Chemicals. Proc. Nat. Acad. Sci. 72 (12):5135-5139 (1975).

11. Loprieno, N., R. Barale, and S. Baroncelli: Evaluation of the Genetic Effects Induced by Vinyl Chloride Monomer (VCM) Under Mammalian Metabolic Activation: Studies In Vitro and In Vivo, Mutat. Res. 40:85-95 (1976).

IDENTIFIERS AND SYNONYMS FOR VINYL CHLORIDE

Chemical Abstracts Service Registry Number 75-01-4
NIOSH RTECS Number KU96250
Chemical Formula C_2H_3Cl

Chlorethene
Chlorethylene
Chloroethene
Chloroethylene
Ethene, Chloro-
Ethylene, Chloro-
Ethylene Monochloride
Monochloroethene
Monochloroethylene
Trovidur
VC
VCM
Vinyl Chloride
Vinyl Chloride Monomer
Vinyl C Monomer

IDENTIFIERS AND SYNONYMS FOR VINYL BROMIDE

Chemical Abstracts Service Registry Number 593-60-2
NIOSH RTECS Number KU84000
Chemical Formula C_2H_3Br

Bromoethene
Bromoethylene
Ethene, Bromo-
Ethylene, Bromo-
NCI-C50373
Vinyl Bromide

IDENTIFIERS AND SYNONYMS FOR VINYLIDENE CHLORIDE

Chemical Abstracts Service Registry Number 75-35-4
NIOSH RTECS Number KV92750
Chemical Formula $C_2H_2Cl_2$

1,1,-DCE
1,1,-Dichloroethene
1,1,-Dichloroethylene
Ethene, 1,1,-Dichloro-
Ethylene, 1,1,-Dichloro
NCI-C54262
Sconatex
Vinylidene Chloride
Vinylidene Chloride (II)

CUMULATIVE LIST OF NIOSH CURRENT INTELLIGENCE BULLETINS

*	1.	Chloroprene	- January 20, 1975
*	2.	Trichloroethylene (TCE)	- June 6, 1975
*	3.	Ethylene Dibromide (EDB)	- July 7, 1975
*	4.	Chrome Pigments	- June 24, 1975 - October 7, 1975 - October 8, 1976
*	5.	Asbestos	- August 8, 1975
*	6.	Hexamethylphosphoric Triamide (HMPA)	- October 24, 1975
*	7.	Polychlorinated Biphenyls (PCBs)	- November 3, 1975 - August 20, 1976
	8.	4,4-Diaminodiphenylmethane (DDM)	- January 30, 1976
*	9.	Chloroform	- March 15, 1976
	10.	Radon Daughters	- May 11, 1976
	11.	Dimethylcarbamoyl Chloride (DMCC) Revised	- July 7, 1976
	12.	Diethylcarbamoyl Chloride (DECC)	- July 7, 1976
	13.	Explosive Azide Hazard	- August 16, 1976
	14.	Inorganic Arsenic - Respiratory Protection	- September 27, 1976
*	15.	Nitrosamines in Cutting Fluids	- October 6, 1976
*	16.	Metabolic Precursors of a Known Human Carcinogen, Beta-Naphthylamine	- December 17, 1976
*	17.	2-Nitropropane	- April 25, 1977
*	18.	Acrylonitrile	- July 1, 1977
*	19.	2,4-Diaminoanisole	- January 13, 1978
*	20.	Tetrachloroethylene (Perchloroethylene)	- January 20, 1978
	21.	*Trimellitic Anhydride (TMA)*	- February 3, 1978
*	22.	Ethylene Thiourea (ETU)	- April 11, 1978
*	23.	Ethylene Dibromide and Disulfiram Toxic Interaction	- April 11, 1978
*	24.	Direct Black 38, Direct Blue 6, and Direct Brown 95 BenzidineDerived Dyes	- April 17, 1978
*	25.	Ethylene Dichloride (1,2-Dichloroethane)	- April 19, 1978
	26.	NIAX *Catalyst ESN	- May 22, 1978
*	27.	Chloroethanes: Review of Toxicity	- August 21, 1978
*	28.	Vinyl Halides - Carcinogenicity	- September 21, 1978

NOTE: Bulletins #1 through #18 have been reprinted as a NIOSH publication, #78-127, for the convenience of those that desire a complete series of Current Intelligence Bulletins. Distribution of this publication and single copies of Bulletins #19 and later are available from NIOSH Publications Dissemination, Division of Technical Services, 4676 Columbia Parkway, Cincinnati, Ohio 45226.

*Cancer related alerts

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Petrochemical guide—20

Vinyl chloride: how, where, who—future

Here is how manufacturing methods, markets, buyers and sellers and economics affect the future of vinyl chloride

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VINYL CHLORIDE has a single important end use as monomer in production of polyvinyl chloride (PVC) and vinyl copolymers. The U.S. production of vinyl chloride expanded at an annual rate of 14 percent during the 1960s, reaching a level of 4 billion pounds in 1970 and 1971. This increase has been accompanied by a steady fall in average F.O.B. selling price from 10 cents/pound to about 4.5 cents per pound in 1970 and 1971. As a result, the imputed value of production has expanded for the decade at a 6 percent rate to $180 million in 1970.

Polyvinyl chloride and other vinyl copolymers are being substituted for older materials on several fronts. Through replacement of steel and iron in piping, wood in construction and packaging, glass and paper in packaging, and leather in clothing, polyvinyl chloride consumption will continue to expand at a rate of about 10 percent through 1975 and beyond. We expect 1975 to see U.S. production of 5.6 billion pounds of vinyl chloride (VCM). This monomer will be sold at an average price of 4.5 cents/pound, and production will therefore be valued at about $280 million (1971 dollars). Production of PVC in Europe is even larger, with 1970 production approximating 5.3 billion pounds. European growth rates have also been somewhat higher, with one enthusiastic source predicting a 1975 PVC production of 9.5 billion pounds.[1] In all likelihood, European PVC consumption will grow less rapidly than in the United States because of the higher per capita consumption prevalent in some major markets in Europe, which makes growth more difficult.

Manufacturing processes for VCM have changed rapidly since 1965. Several new ethylene oxychlorination processes have been employed to shut down older acetylene-based production. These large, new processes now account for over 80 percent of U.S. capacity, and the same process should continue to be employed in expansions through 1975. Recent announcement of an ethane-based process (TRANSCAT)® has raised the yet-unproved possibility of bypassing ethylene cracking entirely, but even a viable TRANSCAT cannot greatly influence the pre-1975 VCM business.

This process switch has also resulted in large changes in the cast of players. In general, some users of VCM have ceased to produce their own monomer, with production undertaken by large, integrated producers of ethylene and chlorine. Dow and B. F. Goodrich are the largest producers and have produced VCM for quite a few years. However, PPG, Shell and Conoco have become the third, fourth and fifth largest VCM producers despite not having been in the business in 1965. We expect this trend toward concentration of large VCM plants among feedstock producers to continue through the next several plants.

The PVC business has also grown at a rapid rate elsewhere in the world. Because of difficulty and expense of shipping, export of VCM has usually constituted a limited

market for U.S. producers, with exports during the 1960s accounting for only a few percent of U.S. production. In 1970 and 1971, however a lack of adequate European capacity caused U.S. VCM exports to increase to some 15 percent of domestic VCM production. This proportion will probably return to less than 6 percent by 1975.

MANUFACTURE

Most present-day vinyl chloride monomer (VCM) capacity relies on the so-called balanced oxychlorination process to convert chlorine and ethylene to VCM. There are, nonetheless, several older process routes which are discussed below in the approximate order of their commercialization.

1. Catalytic addition of hydrochloric acid to acetylene

$$HC \equiv CH + HCl \xrightarrow[+\ HgCl_2]{\text{Activated carbon}} CH_2 = CHCl$$

Acetylene — Hydrochloric acid — VCM

The earliest plants of this sort employed carbide-derived acetylene and hydrochloric acid derived by combusting hydrogen with chlorine. The catalyst for this addition is mercuric chloride absorbed on a carrier such as activated carbon. The reaction is simple and of high yield when compared to subsequent VCM processes, thereby allowing simple product purification, no sizable waste disposal problem, and low capital and operating costs. Carbide acetylene and purposely produced hydrochloric acid were gradually replaced with less expensive petroleum-derived acetylene and byproduct hydrochloric acid (which also coincided with major relocations to the U.S. Gulf Coast), but raw material costs remained high relative to newer processes. Some VCM is still produced with this process, but these surviving plants are very tightly integrated with other acetylene-related units and have been gradually disappearing.

2. Balanced ethylene/acetylene VCM production

$$CH_2 = CH_2 + Cl_2 \longrightarrow CH_2Cl - CH_2Cl$$

Ethylene — Chlorine — Ethylene dichloride (EDC)

$$CH_2Cl - CH_2Cl \xrightarrow{900\text{–}950^\circ F} CH_2 = CHCl + HCl$$

EDC — VCM — Hydrochloric acid

$$HC \equiv CH + HCl \longrightarrow CH_2 = CHCl$$

Acetylene — Hydrochloric acid — VCM

There are instances where the first two steps of this process—chlorination of ethylene to EDC and cracking of EDC to yield VCM plus hydrochloric acid—have been applied without an acetylene unit. Ethyl Corp. has applied this technique, with byproduct HCl used to produce ethyl chloride for manufacture of tetraethyl lead antiknock compounds. Most producers, however, cannot justify sufficient end uses of the HCl byproduct. The result was the balanced ethylene/acetylene complex (as employed by Union Carbide and Monsanto at Texas City, Texas). Plants were sized so that the acetylene-based production consumed most excess hydrochloric acid fom EDC cracking to produce VCM directly. This process reduces by half the dependence upon acetylene as a feedstock, but no new examples have been constructed in the United States in the past few years.

3. Balanced oxychlorination process

Direct chlorination

$$CH_2 = CH_2 + Cl_2 \longrightarrow CH_2Cl - CH_2Cl$$

Ethylene — Chlorine — EDC

Oxychlorination

$$CH_2 = CH_2 + HCl + \tfrac{1}{2}O_2 \rightarrow CH_2Cl - CH_2Cl + H_2O$$

Ethylene — EDC — Water

Cracking

$$CH_2Cl—CH_2Cl \xrightarrow{900\text{–}950^\circ F} CH_2 = CHCl + HCl$$

EDC — VCM

The difference between these processes and the earlier uses of EDC cracking is the second reaction above to (1) prevent exporting a large HCl byproduct and (2) eliminate the need for acetylene-feedstock. This reaction is essentially a variant of the Deacon process to convert HCl to more valuable chlorine.

$$2\ HCl + \tfrac{1}{2}\ O_2 \longrightarrow Cl_2 + H_2O$$

While the Deacon process has not been a commercial success because of technical problems with corrosion and product purification expense, oxychlorination has overcome these problems by immediately capturing the chlorine *in situ* to form EDC. The combined EDC streams are then cracked and the resultant HCl recycled to close the loop. As mentioned above, most presently employed processes—including Goodrich, Dow, Stauffer and PPG—use some variation of balanced oxychlorination.

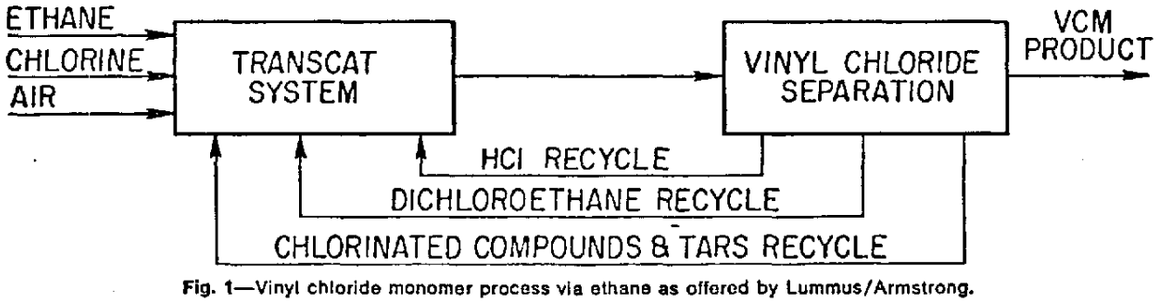

Fig. 1—Vinyl chloride monomer process via ethane as offered by Lummus/Armstrong.

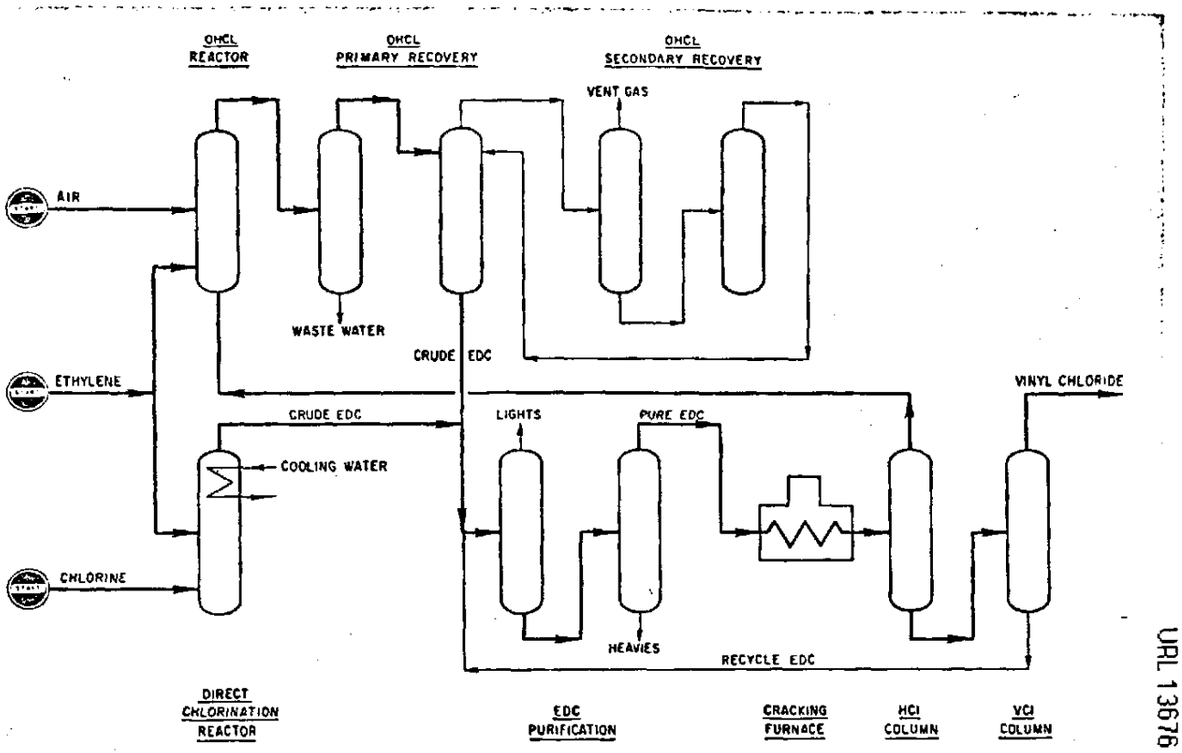

Fig. 6-2—Vinyl chloride by oxychlorination by B.F. Goodrich.

4. Single-step chlorination and cracking of ethane (TRANSCAT process)

$$CH_3—CH_3 \xrightarrow[\text{salt}]{\text{molten}} CH_2 = CH_2$$

Ethane — Ethylene

$$CH_2 = CH_2 + Cl_2 \longrightarrow CH_2\,Cl—CH_2\,Cl$$

Ethylene — Chlorine — EDC

$$CH_2\,Cl—CH_2\,Cl \xrightarrow[\text{salt}]{\text{molten}} CH_2—CHCl + HCl$$

EDC — VCM — Hydrochloric acid

$$2\,HCl + \tfrac{1}{2}\,O_2 \xrightarrow{\text{molten salt}} Cl_2 + H_2O$$

The recently announced TRANSCAT process involves the development to a pilot stage of an ethane-based route which foregoes the separate purification of ethylene (see Fig. 6-1). Ethane, chlorine, air and excess hydrochloric acid (if desired) are fed to a molten salt bath with an extremely short residence time and a high temperature, where all of the above reactions apparently occur simultaneously. The potential licensors (Lummus/Armstrong Cork) claim above 95 percent VCM yield on chlorine and 80 percent VCM yield on ethane fed. Even more chemically revolutionary is the claim that chlorinated wastes which are produced may be partially recycled to the reactor to result in additional VCM. The indicated economic advantage (see "Economics") of ethane as a feedstock might make this the VCM process of the future, should the process prove to be commercially viable.

Popular VCM processes. While oxychlorination has been the process route chosen for all recent VCM plants in the United States and most of the rest of the world, this has not decreased the competition among different processes and licensors. There are several competing processes which have demonstrated their commercial feasibility. The following three oxychlorination processes—on which significant information has been published—are representative of most manufacturing facilities.

1. B. F. Goodrich oxychlorination (Badger). This process was the first successful oxychlorination process (1965), with the initial 400-million-pound/year unit installed at Goodrich's plant in Calvert City, Ky. There are about 8 plants which utilize this process, having an aggregate capacity of about 4 billion pounds/year.[2]

As is true of all balanced oxychlorination processes, the over-all material balance involves feeding ethylene and chlorine and production of vinyl chloride (see Fig. 6-2). Yields are certainly in the 90 percent range (and may exceed 95 percent) on both primary feedstocks. The yield losses involve production of light and heavy ends which boil above and below EDC. These byproducts consist primarily of C_1 and C_2 chlorinated organics, some of which are suitable as feedstocks for production of chlorinated solvents (carbon tetrachloride, perchloroethylene), while the balance require disposal.

The first of three segments of the process is direct

addition of chlorine to ethylene to produce ethylene dichloride (EDC). This reaction is essentially stoichiometric in both reactants, with chlorine usually maintained in a slight excess. The reaction is liquid phase with a dissolved catalyst and mildly exothermic. Reactor temperature and pressure are controlled by cooling water heat removal. Following the reactor, the EDC product is fed to a two-step purification train to remove light and heavy ends (the same train processes two other EDC streams).

The second major operation consists of cracking EDC to produce vinyl chloride and anhydrous hydrochloric acid. The cracking occurs at 900-1,000° F in a direct-fired furnace which is packed with a catalyst (pumice has been a traditional choice). Conversion of EDC is typically in the 50-60 percent range to optimize the costs between coking cycle, utilities cost and yield. The hot product gases are quenched by direct contact with a condensed recycle stream of the same composition, prior to fractionation. In the HCl column, anhydrous HCl is removed overhead for use in the oxychlorination unit. The VCM column produces VCM as an overhead product meeting finished product specifications, and produces a recycle EDC stream of unconverted EDC. This stream is purified in the common EDC columns prior to recycling to the cracking furnaces. The purification step is required to prevent fouling of reaction surfaces in the cracking furnace.

These two previous process sections offer relatively little advantage over older processes—they constitute an unbalanced EDC cracking operation (such as practiced by Ethyl) which produces HCl as a byproduct. The third section of the B.F. Goodrich and other oxychlorination processes involves conversion of this excess HCl to EDC. Air, ethylene and HCl are charged to a fluidized catalyst bed at a moderately high temperature and somewhat elevated pressure. The reaction to produce EDC (given above) yields water byproduct, which is rejected as the product vapor is condensed. The first step of condensation produces a crude EDC product, while the gases (primarily diluent nitrogen) must be fed to a secondary absorber to recover a second stream of EDC by absorption/stripping. The tail gases are vented, while crude EDC is fed to the common EDC finishing train.

The oxidation of HCl to Cl_2 is highly exothermic and the subsequent addition of Cl_2 to ethylene is mildly exothermic. As a result, the oxychlorination reactor, is cooled by generating steam, which brings the whole process closer to self-sufficiency on steam supply.

The net effect of this crucial section is thus the conversion of HCl, ethylene and air to a VCM precursor. While the process is depicted as balanced, design and operating changes allow any individual plant to produce or accept either HCl or EDC as local conditions warrant.

2. Toyo Soda oxychlorination (see Fig. 6-3). A process very similar to that of B. F. Goodrich has been employed in several Japanese plants. The essential design differences appear to be: (1) the use of a fixed bed reactor for oxychlorination, as opposed to the B. F. Goodrich fluid bed; (2) use of a hot oil reactor coolant and external steam generation, and (3) incorporation of a specific EDC dehydrator column not shown in the B. F. Goodrich publications. None of these differences are

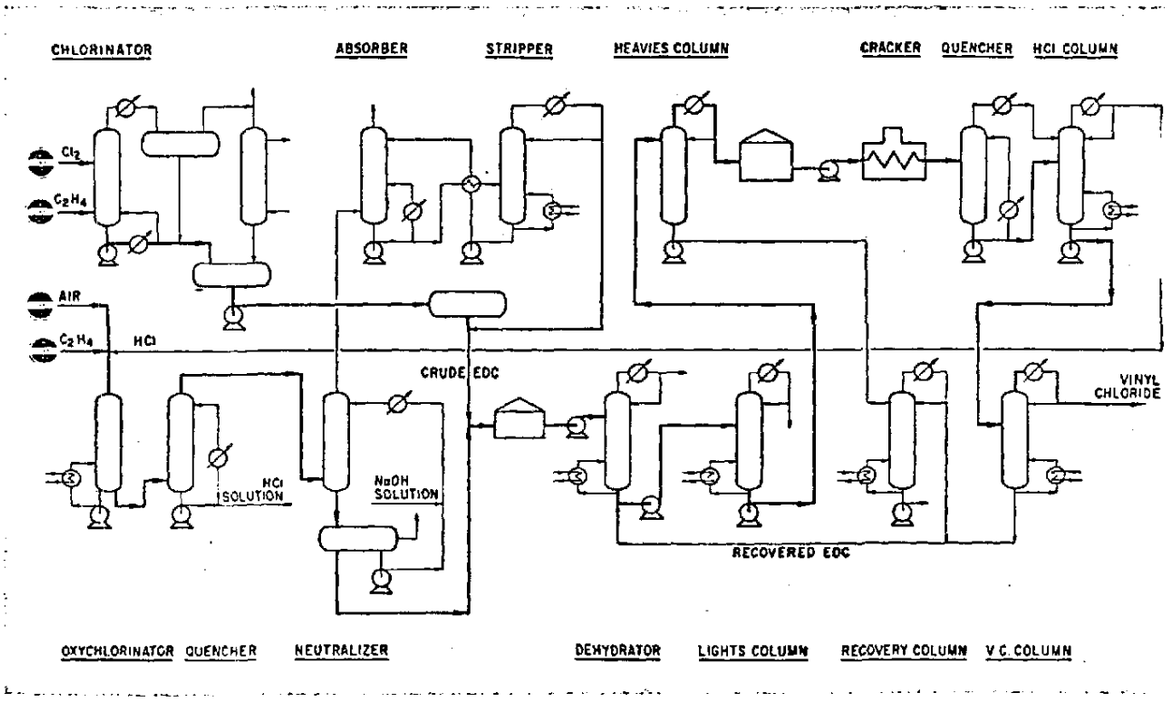

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Fig. 6-3—Toyo Soda's oxychlorination vinyl chloride process.

major; the processes should be roughly competitive based upon published data.[3]

3. Stauffer Chemical oxychlorination. This is again very similar to the earlier oxychlorination processes. Minor changes in the routing of streams, small differences in catalyst performance, and features of the mechanical design are all that differentiate between the published information for this process and the previous two. It is noteworthy that Stauffer published an estimate of 3.7 billion pounds/year of vinyl chloride capacity in 17 plants utilizing this process.[4]

4. Monsanto oxychlorination. There are several licensees for this similar process.[5]

5. Dow oxychlorination. Only Dow and foreign subsidiaries have used the Dow VCM process, and no indication of a willingness by Dow to license to others has been published.

6. Union Carbide (Lummus) balanced acetylene/ethylene process. No recent examples of this process have been constructed in the United States, but a Union Carbide venture using a Wulff process acetylene/ethylene plant in Brazil is employing this process to consume part of the production. Complete startup of this plant is planned for 1972.

The basic flow scheme is shown in Fig. 6-4. Ethylene and chlorine produce EDC, which is cracked to yield HCl and VCM; the process is very similar in this area to the above processes. However, instead of using oxygen and ethylene to convert the byproduct HCl to EDC, the balanced process then involves the older acetylene route. The reaction is a vapor phase reaction over $HgCl_2$/carbon catalyst with a slight HCl excess. A circulating coolant removes reaction heat to control the reaction temperature to about 400° F. Conversion is less than complete in some plants, requiring recycle of acetylene and HCl, but the reaction yields are 95 percent or greater. Therefore, the removal of light and heavy byproducts is simple. This results in low capital and operating costs for the process, but the use of acetylene at current or projected U.S. prices makes this process less than competitive with balanced oxychlorination (see "Economics").

7. Others. Pechiney-Saint-Gobain offers combined production of chlorinated solvents and vinyl chloride in flexible proportions. A single plant at Saint Auban, France, has operated since the spring of 1970 to produce about 120,000 metric tons/year of VCM with this process.[6]

Diamond Shamrock/deNora offer "Dianor," a process to produce and crack EDC which is aimed at developing countries with no ethylene complexes.[7] The process operates on ethylene as low as 60 percent concentration and produces HCl byproduct, which would leave the process uncompetitive under any but the special circumstances of small, developing chemical markets with tariff protection.

Feedstock availability. The importance of feedstock cost to VCM producers has resulted in the entry to the VCM market of large, integrated chlorine and ethylene producers (see "Individual Companies" and "Economics"). Future manufacturing efforts will be largely influenced by trends in both of these related fields. A brief review of trends follows:

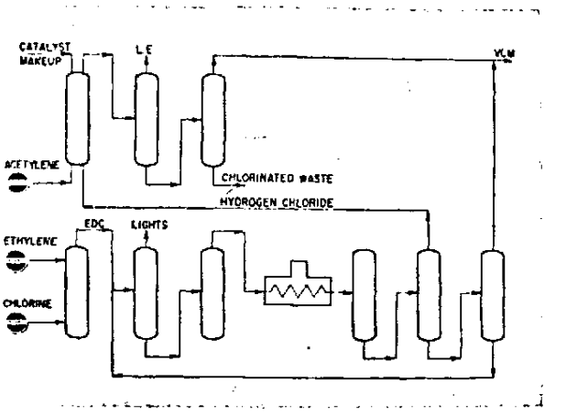

Fig. 6-4—Author's interpretation of the balanced VCM process as announced by Union Carbide (Lummus).

TABLE 6-1—Properties of VCM[8]

Mol. wt	62.50	
Specific gravity	0.9834	20°/20 °C
Melting point	−153.8° C	(−244.6 °F)
Boiling point	−13.81° C	(7.1 °F)
Flash point	−108° F	
Maximum allowable concentration (ppm by volume)	500	
Explosive limits % by volume in air	Lower 4 Upper 22	

Ethylene production in the United States has been drifting away from the traditional patterns. Until recently more than 80 percent has been manufactured from ethane and propane cracking and about the same proportion located in the U.S. Gulf Coast.[8] Some recent plants have involved movement toward the north and Puerto Rico and cracking of heavy feedstocks. With developing shortages of natural gas, a continuing erosion of the competitive advantage of cracking Gulf Coast ethane and propane is likely, and cracking of heavier feedstocks will probably result in higher ethylene prices. With ethylene much more difficult to ship large distances than either vinyl chloride or chlorine, a tendency to locate vinyl chloride production near ethylene plants should continue.

Chlorine is the other major feedstock, with VCM accounting for about 15 percent of U.S. chlorine production in recent years. Largely as a result of slumping VCM demand (which declined silghtly in the first half of 1971), chlorine demand has been slack in the 1969-1971 period. However, as various chlorinated products resume their growth trends between 1971 and 1975, chlorine demand should once again require expanded capacity. Given the considerable economies of scale in chlorine/caustic production, the largest and most integrated producers will retain their competitive advantage in VCM.

Very substantial electrical energy requirements for chlorine production will force locations to sources of low-cost power. While nuclear fuel and coal are in the running as long-term suppliers of low cost power, petroleum and natural gas remain necessary until at least 1980. Therefore, availability of petroleum and natural gas fuels will help determine chlorine plant locations until at least 1975.

These trends indicate that manufacturing locations for VCM are likely to be heavily influenced by availability of inexpensive hydrocarbon feedstocks and fuels, with relative labor and construction costs, water and transportation facilities acting as less important constraints.

Physical properties. See Table 6-1.

MARKETS

U.S. consumption of VCM was about 3.3 billion pounds in 1970, with 664 million pounds being exported. Consumption of VCM is almost entirely for production of polyvinyl chloride resins and copolymer resins (propylene, ethylene and vinyl acetate are commonly copolymerized with VCM). Domestic consumption is projected to grow about 10 percent annually from the 1970 level of 3.3 billion pounds to 5.3 billion pounds in 1975. Export markets will decline from the 16 percent of U.S. production experienced in 1970 to the more usual level of 5-6 percent of production, or 300 million pounds, by 1975.

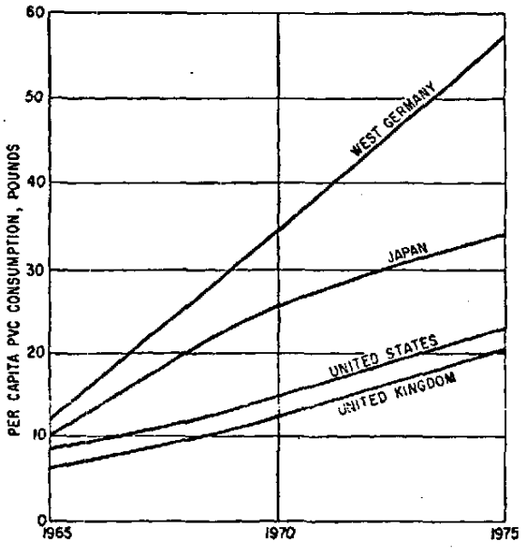

Fig. 6-5—Per capita consumption of polyvinyl chloride.[10]

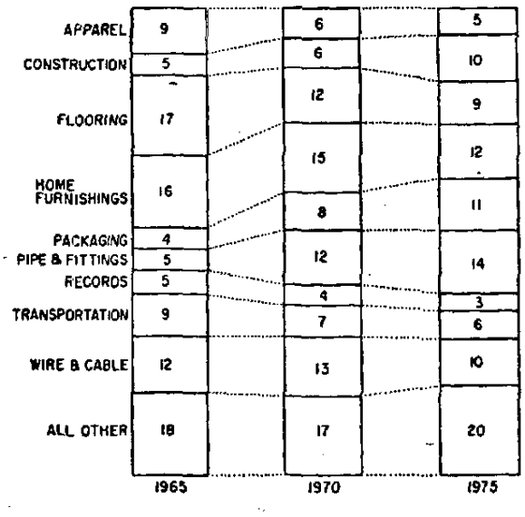

Fig. 6-6—End use markets for PVC.[10]

End uses of PVC are characterized by more variety than most other commodity resins. Physical properties of PVC vary from the soft and flexible plasticized varieties used in dolls to the strong and rigid PVC pipe invading the construction markets. Fig. 6-5 demonstrates the rapid growth in per capita consumption which has resulted from this variety of properties.[10] As a result, PVC consumption is also less vulnerable to the loss of any single end use market.

The more rapidly growing markets for PVC are construction products, packaging, pipe and fittings. These areas should exceed the 10 percent growth rate of the overall PVC market. Segments which are more mature and will grow at less than 10 percent include apparel, flooring, home furnishings, phonograph records, transportation equipment, and wire and cable coatings. An estimate of the 1965, 1970 and 1975 market share of each category is given in Fig. 6-6. While some categories will have declined relative to all PVC consumption, actual volume sold in 1975 is projected to increase in all categories.[10]

Construction uses for PVC include vinyl-coated wall coverings, and strips of PVC sheet to serve as water stops in walls and weatherstripping. The largest potential, however, probably belongs to PVC siding and window frames, which are rapidly growing competitors of older wooden and aluminum products. The construction market should grow in excess of 20 percent annually for the next five years.

The packaging application of PVC has been growing very rapidly in recent years. There are environmental pressures to restrict PVC content of packaging because of HCl released when packaging is incinerated, but such restrictions will act to slow this growth area before 1975, not to reverse the trend. Packaging consumption of PVC grew at above 25 percent annually in the last five years, and should grow at 15-20 percent for the next five years. After 1975, however, look for growth to slow considerably as effective control of HCl emissions causes other materials to replace PVC in some applications.

Use of PVC pipe and fittings has benefitted from the accelerating change of U.S. building codes to allow plastic drain, waste and vent piping. A.D. Little has projected a 1975 consumption of 1 billion pounds of plastic piping, with PVC representing a large share.[11] The PVC in this application is often blended with chlorinated polyethylene resin. Competition with acrylonitrile-butadiene-styrene (ABS) resins and styrene-acrylonitrile (SAN) resins will be important in determining the actual growth of this PVC application, but 15 percent is a likely growth rate if PVC prices remain below those of ABS and SAN resins.

Among the more mature PVC markets, use of PVC in transportation equipment should continue at a relatively high growth rate. Further penetration of the automobile market is not a major hope for PVC, since seat

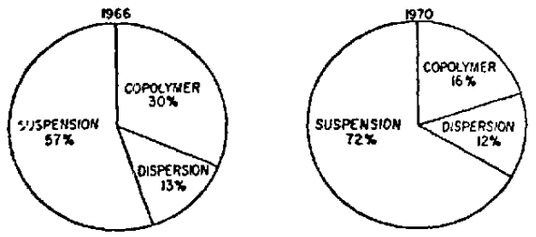

Fig. 6-7—PVC production by type according to the U.S. Tariff Commission.

covers, headliners and dashboards have all been heavily penetrated. As a result, this end use will grow at about the rate automobile production grows. While other transportation uses will increase, look for this segment to grow at 8-9 percent over-all.

Uses of PVC in apparel, flooring, home furnishings and wire coating are mature segments. Growth of these segments should keep pace with real GNP growth at about 5 percent annually through 1975.

Another possible categorization of PVC uses is by the processing methods being used to meet the above markets. Table 6-2 presents a breakdown by processing methods, again reflecting the diversity of PVC markets.

Polymer producers. One reason for the varied properties of PVC resin is the diversity of polymerization methods employed and another is the large number of PVC producers, each with a slightly different product line. While 65 percent of VCM was polymerized captively in 1960, this percentage declined rapidly as older acetylene-based plants were replaced with larger ethylene-based plants. Today companies such as Dow and Shell are exclusively merchant sellers of VCM, while PVC producers such as Monsanto and Union Carbide have discontinued VCM manufacture. As a result, only about 40 percent of VCM was captively consumed in 1970, and the percentage will probably be closer to 30 percent in 1975. The 21 companies currently producing PVC are listed in Table 6-3, together with capacity by region. Of these 21 companies, 7 also produce VCM (see Table 6-5).

A final characterization of PVC production is the type of polymerization employed. Suspension homopolymer resins have been an increasing fraction of PVC production in recent years, mostly at the expense of copolymer resins, while dispersion resins have maintained a relatively constant share. Fig. 6-7 presents a breakdown of PVC by method of polymerization.

World markets. During the 1960s, exports of VCM averaged less than 5 percent of domestic production. VCM must be shipped and stored either under pressure or in a refrigerated tank. The relative difficulty of shipping, low selling price in relation to freight cost, and ready availability of VCM technology has created a strong tendency to produce VCM locally rather than import for an extended period. In 1969, 1970 and 1971, however, rapid expansion of European VCM demand and lagging production capacity led to abnormally large imports from the U.S. Exports accounted for a high of 16 percent of domestic VCM production in 1970. As added capacity comes onstream in Western Europe and developing countries rush to build VCM plants, U.S. exports of VCM will decrease again to 5-6 percent of production or lower.

U.S. exports of PVC resin are also minimal; in 1969 and 1970, about 5.5 percent and 6 percent of the U.S. PVC sold was exported. Two reasons for this are the

TABLE 6-2—Processing methods for PVC[39]

	Share of market, %
Extrusion (wire, film, sheet and general extrusion)	40
Calendering (film, sheet and coating)	35
Molding (blow, injection, roto, compression)	10
Coating (dip, knife, roll, spray, lamination)	10
Other	5

TABLE 6-3—PVC producers in the United States,[38] Jan. 1, 1971

Northeast		
Borden	Leominister, Mass.	12 companies
Diamond-Shamrock	Delaware City, Del.	13 plants
Firestone	Pottstown, Pa.	1,300 MM lbs. capacity
B. F. Goodrich Chemical	Pedricktown, N. J.	
Goodyear Tire & Rubber	Niagara Falls, N. Y.	
Great American Plastics	Fitchburg, Mass.	
Hooker	Burlington, N. J.	
Monsanto	Springfield, Mass.	
Olin	Assonet, Mass.	
Pantasote	Passaic, N. J.	
Stauffer	Delaware City, Del.	
Tenneco	Burlington, N. J.	
	Flemington, N. J.	
Southeast		
Air Products	Pensacola, Fla.	5 companies
Continental Oil	Aberdeen, Miss.	5 plants
Firestone	Perryville, Md.	450 MM lbs. capacity
Pantasote	Point Pleasant, W. Va.	
Union Carbide	S. Charleston, W. Va.	
Midwest		
Air Products	Calvert City, Ky.	6 companies
Allied Chemical	Painesville, Ohio	8 plants
Borden	Illiopolis, Ill.	1,000 MM lbs. capacity
General Tire	Ashtabula, Ohio	
B. F. Goodrich Chemical	Henry, Ill.	
	Avon Lake, Ohio	
	Louisville, Ky.	
Uniroyal	Painesville, Ohio	
Southwest		
Diamond-Shamrock	Deer Park, Texas	4 companies
Ethyl	Baton Rouge, La.	4 plants
Goodyear Tire & Rubber	Plaquemine, La.	600 MM lbs. capacity
Union Carbide	Texas City, Texas	
Far West		
American Chemical	Long Beach, Calif.	3 companies
B. F. Goodrich Chemical	Long Beach, Calif.	3 plants
Keysor	Saugus, Calif	200 MM lbs. capacity
		21 total companies **33 total plants** **3,550 MM lbs. total capacity**

TABLE 6-4—Western European PVC consumption (thousands of metric tons)

Year	EEC	EFTA	Spain	Other	Total Western Europe
1962	506	227	17	40	795
1963	610	255	26	52	943
1964	769	308	29	72	1,178
1965	843	339	33	56	1,271
1966	930	359	46	55	1,410
1967	1,061	401	59	141	1,661
1968	1,227	472	71	155	1,925
1969	1,505	525	91	140	2,261
1970*	1,598	557	97	148	2,400
Growth rate (1962-1970)	15%	12%	24%	18%	15%
1975 Consumption*	2,575	820	220	285	3,900*
Projected growth Rate (to 1975)*	10%	8%	18%	14%	10%

Source: European Chemical News and Oil, Paint and Drug Reporter, Oct. 26, 1970, plus authors' estimates.*

rapidly expanding domestic markets for PVC and the high relative freight costs. Furthermore, tariff barriers are high—20 percent or more—between European countries, as well as between Europe and the United States.[12] Despite this, the specific properties required by resin users remain the most difficult barrier to a large world trade in PVC. In a recent report of the Standard Research Institute[13] projections of the world output of PVC for 1970 and 1980 are compared. The percentages accounted for by each producing area are as follows:

	1970	1980
North America	26.5%	26.5%
Western Europe	41.3	39.7
Japan	16.5	17.9
Others	15.7	15.9
	100.0%	100.0%

While special purpose resins sales to developing markets will continue to be an attractive market, PVC resin exports will remain a small market at 5 percent or less of production.

The European PVC market is considerably larger than the U.S. market (see Table 6-4), based upon Europe's large population and greater per capita consumption. This will allow European producers to build large, competitive VCM facilities to serve their own markets. As U.S. producers encounter higher ethylene costs based upon cracking heavier feedstocks and higher chlorine costs from more expensive electric power, exporting to the European VCM market should cease to be attractive to U.S. producers.[14]

Japanese PVC producers also represent a sizable market for VCM, but domestic Japanese production is ample to provide the estimated 2.4 billion pounds which will be required in 1972. Estimated VCM capacity is in the neighborhood of 3 to 3.3 billion pounds/year (see Table 6-6), indicating either sizable exports or low operating rates for Japanese VCM producers.

A partial listing of foreign VCM producers is given in Table 6-6. Since this is not an exhaustive listing, total capacity figures are not available. However, the per capita consumption of VCM is even higher in Europe than in the United States and trends toward oxychlorination are evident.

INDIVIDUAL COMPANIES

Table 6-5 lists U.S. producers of VCM as of 1972. Of the total capacity shown, 10 percent is based on acetylene and 8 percent on ethylene without oxychlorination capability. These plants must be considered vulnerable to continued construction of large oxychlorination facilities. The remaining 5 billion pounds (82 percent) consists of modern, apparently competitive oxychlorination plants. Also noteworthy is the concentration of over 70 percent of VCM capacity on the U.S. Gulf Coast. With the exception of PPG's Puerto Rican plant, all recent capacity additions have been in Texas and Louisiana.

The expansion of VCM capacity from 2.4 billion pounds/year in 1965 to about 6 billion pounds/year by 1971 was at an annual rate of 18 percent. The actual rate of new capacity construction has been even more rapid, with fully half of the 1965 capacity being shut down in the same period. Eighty percent of 1971 capacity is less than 6 years old.

TABLE 6-5—U.S. producers of VCM

Producer	Location	Nameplate capacity (MM lbs./yr.)	Process
Allied	Baton Rouge, La.	300	Oxychlorination
American Chemical (ARCO-Stauffer)	Watson, Calif.	170	Stauffer oxychlorination
Monochem (Borden-Uniroyal)	Geismar, La.	300	Acetylene
Conoco	Lake Charles, La.	600	Stauffer oxychlorination
Dow	Plaquemine, La.	340	Dow oxychlorination
	Freeport Texas	180	Dow oxychlorination
	Oyster Creek, Texas	700	Dow oxychlorination
Ethyl	Baton Rouge, La.	270	Ethylene/EDC cracking
	Houston	150	Ethylene/EDC cracking
Goodrich	Calvert City, Ky.	1,000	Goodrich oxychlorination (multiple train)
PPG	Lake Charles, La.	300	Oxychlorination
	Puerto Rico	500	Oxychlorination
Shell	Houston	800 (Expanding)	Stauffer oxychlorination
	Norco, La.	800 (1974)	Stauffer oxychlorination
Tenneco	Houston	255	Acetylene
	1972 Total	5,865	

Source: Many published estimates as interpreted by the authors. Note that effective capacity probably does not equal nameplate capacity. A reasonable capacity figure would probably be 80% of the above rates. *Oil, Paint and Drug Reporter*, Oct. 11, 1971, has the most complete listing.

Among individual companies, Dow has about 19 percent of VCM capacity, and about 23 percent of oxychlorination capacity. Dow's position as a capacity leader among ethylene, chlorine and chlorinated solvents producers leaves no doubt of Dow's long-term position as a VCM producer. Raw materials costs are crucial to VCM economics, being roughly equally split between chlorine and ethylene (see "Economics"). In addition, byproduct chlorinated hydrocarbons from oxychlorination are routinely absorbed into Dow's production of perchloroethylene and carbon tetrachloride. At the present time, this VCM is largely sold in the merchant market. While Dow has extensive experience in production of bulk polymers, Dow has chosen to remain a merchant supplier and has discontinued production of PVC.

The second largest VCM capacity belongs to B. F. Goodrich at Calvert City, Ky. Two or three trains at this site employ Goodrich's oxychlorination process (see "Manufacture"), and are notable in being the only sizeable plants located in the northern or eastern United States. Goodrich has captive use for most or all of this VCM, but has made no recent move to expand beyond their existing 17 percent capacity share. Both ethylene and chlorine for this plant are produced by Goodrich at Calvert City.

PPG has moved into second place with a 14 percent capacity share. Plants in Lake Charles, La., and Puerto Rico benefit from large internal chlorine sources and chlorinated solvents business to absorb byproducts, but ethylene is purchased in both cases. As is the case with most recent expansions, the majority of VCM produced moves in the merchant market.

The fourth and fifth largest producers are oil companies with large ethylene capacity but insufficient chlorine for VCM production. Shell has recently completed and started up 12-14 percent of U.S. industry

TABLE 6-6—Foreign VCM producers

Country	Company	City	Annual capacity (thousand metric tons)	Process/completion
EUROPE				
Belgium:	BASF	Antwerp	120	Stauffer
	Solvic	Jemeppe	200	Solvay—ICI
	Limburgse Vinyl	Tessenderloo	200	Goodrich
Czechoslovakia:	Technoexport	Novaky	50	Goodrich/Hoechst
Finland:	Pekema Oy	Porvoo	53	Solvay/ICI
France:	DAUFAC	.....	90	Ethylene (expanding)
	Pechiney-Saint-Gobian	LaVera	120	Own (1972)
	.....	.....	120	Ethylene-based (1972)
	Solvay	Tavaux	200	Balanced acetylene/ethylene
Greece:	Ethyl Hellas	.....	25	Ethyl EDC cracking
Italy:	ANIC	Ravenna	250	Stauffer (completion)?
	Montedison	Porto Marghera	250	Goodrich (1971)
	Rumianca	Cagliari	180	PPG (1972)
Netherlands:	AKZO	Botlek	100 (expanded)	Goodrich/Stauffer
	Shell	Pernis	300	.....
Rumania:	Industrial Import	Rimnico Vilcea	75	N. A.
Spain:	Monsanto Iberica	Tarragona	36	Monsanto/Ethylene
	Oxycros	Puertollano	50	Goodrich
	Viniclor	Martorell	80 (planned)	Solvay/ICI (1972)
Sweden:	Kemanord	Stenungsund	65	Ethylene
U. K.:	B. P. Chemicals	Baglan Bay, Wales	75	Goodrich
	British Geon	.....	260	Acetylene
	ICI	Hillhouse	140	Oxychlorination
	.....	Runcorn	N. A.	Oxychlorination
USSR:	Techmashimport	Dzerjinski	N. A.	P-S-G (1972?)
	.....	Gorki	30	Stauffer (1973?)
West Germany:	BASF	.....	33	Balanced
	ChemWerke Huels	Marl	300	Huls (1972)
	Hoechst	Knapsack	365 (expanded)	Goodrich/Hoechst
	Knapsack AG	Koln	60 (planned)	Goodrich/Hoechst
	Wacker Chemie	Burghausen	100	Acetylene (1971)
LATIN AMERICA			N. A.	
Argentina:	Electroclor SAIC	Capitan Bermudez	50 (planned)	ICI (1973)
	Industrias-Dow	Bahia Blanca	50 (planned)	Dow (1974)
Brazil:	Consorcio-Paulista	Elclor	100	Ethyl/Solvay/ICI
	.....	Sao Paulo	100	Solvay/ICI
	Union Carbide	N. A.	85	Balanced ethylene-acetylene (1972)
Chile:	Empressa Nationale de Petroleo	Concepcion	15 (plan)	N. A.
	Petroquimica-Dow-ENAP	Concepcion	15 (plan)	Dow
Mexico:	PEMEX	Paratitos	70	Scientific Design
Venezuela:	B. F. Goodrich/IVP/others	El Tablazo	50	B. F. Goodrich (1973)
AFRICA/MIDDLE EAST				
Egypt:	General Organization for Industr	Alexandria	43 (planned)	N. A.
Turkey:	Petkim Petrokimya	Izmit	30	Solvay/ICI
	.....	Aliaga	95 (planned)	1974
	.....	Yarimca	27 (planned expansion)	1972
ASIA/PACIFIC				
Australia:	Goodrich	Altona	N. A.	Goodrich
Japan:	Asahi-Penn Chemical	Goi	145 (EDC)	PPG
	Central Chem.	Kawasaki	90 (EDC)	Toyo Soda
	Chiba VCM	Chiba	160	Stauffer
	Chisso Petro-chemical	Minamata	55	Toyo Soda (1972)
	Japanese Geon	.....	130	Balanced, Goodrich
	Kanegafuchi	Osaka	120	Stauffer
	Kaaei Mizushima	Misushima	50	Monsanto/Scientific Design
	Kureha	.....	120	Balanced
	Mitsubishi-Monsanto	Yokkaichi	.....	.....
	Mitsui	Nogoya	60	Mitsui
	Mitsui Toatsu	Iwakuni	N. A.	Scientific Design
	Nihon VCM	Nihon	80	Stauffer
	Senpoku Petro-chemicals	Osaka	120	Mitsui
	Toyo Soda	Tokoyama	110	Toyo Soda
	.....	Yokkaichi	100	Toyo Soda
Korea:	Korean Pacific Chemical	Ulsan	60	Dow
Taiwan:	Chinese Petroleum	Kaohsiung	64	Monsanto/Tokoyama
	Taiwan VCM	Toufen	60 (planned)	Union Carbide (1972)
Thailand:	Thai Plastic	Bangkok	40	Dynamit Nobel

Source: Authors' estimate based on many published sources. This list is not intended to be comprehensive, but to list most major producers.

capacity at Houston. Ethylene comes from a gas oil cracker with 1 billion pounds/year capacity, but required chlorine is purchased externally. Shell produces chlorine and other chlorinated organics beside VCM, but has apparently chosen not to expand chlorine capacity for use in VCM. With recent announcement of a similar scale VCM unit in Norco, La., Shell will become the largest VCM producer by 1975. Conoco has 10 percent of industry capacity at Lake Charles, with ethylene provided by ethane/propane cracking and chlorine requirements purchased. It is reasonable to watch major ethylene and chlorine producers for the next VCM units.

HISTORICAL DATA

Table 6-7 presents data based on U.S. Tariff Commission reports for 1958 through 1969 and the authors' estimates for 1975. These data show a steady rise in the production of VCM, excepting a slump in 1967, when the industry was particularly plagued with overcapacity. Production has grown at over 17 percent per year for the past five years. Average sales price has continually dropped because oxychlorination of ethylene, which is accounting for an ever-increasing proportion of VCM production, is considerably cheaper than the acetylene route, and because of economies of scale. Because of these offsetting

TABLE 6-7—U.S. historical data: VCM, 1959 to 1975

Year	Number of producers	Production MM lb./yr.	Sales MM lb./yr.	Average price, ¢/lb.	Total value of prod'n, $MM
1959...	10	978	329	11	108
1960...	12	1,037	352	10	104
1961...	12	1,044	424	8.1	85
1962...	12	1,311	516	7.5	98
1963...	13	1,435	501	7.0	100
1964...	13	1,614	598	6.3	102
1965...	13	2,000	688	6.1	122
1966...	13	2,500	836	5.9	148
1967...	13	2,424	952	5.3	128
1968...	12	2,969	1,463	4.6	136
1969...	11	3,738	2,356	4.4	164
1970...	9	4,000	2,520*	4.5*	180*
1975...	10*	5,600*	4,200*	4.5*	252*

Source: U.S. Tariff Commission
* Author's estimates, with price projection in 1971 dollars.

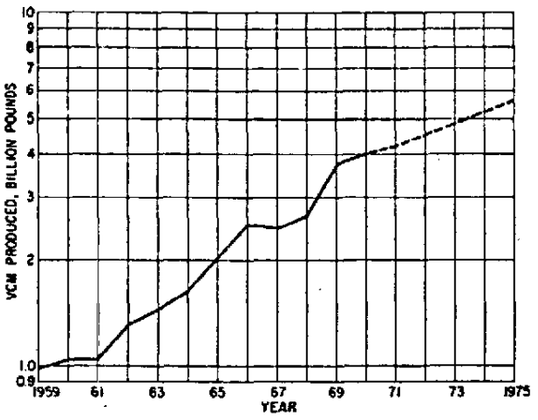

Fig. 6-8—VCM production in the United States, U.S. Tariff Commission and authors' estimates.

trends, the total value of production has increased only 6 percent per year since 1964. However, it is believed that the average sales price (real dollars) will hold steady through 1975 because of rising ethylene and chlorine costs and that the growth rate of VCM production will be closer to seven percent per year from 1970 to 1975.

The future of VCM is directly tied to the future of PVC, and PVC consumption in the United States is expected to show an annual growth rate of 10 percent from 1970 to 1975. The trends of VCM production, price and value are shown in Figs. 6-8, 6-9 and 6-10.

ECONOMICS

The price of VCM has exhibited the typical downward trend of maturing petrochemical monomers. The major reasons for this trend have been the consistently improving technology, the much larger scale of existing production facilities, and the considerable decrease in the price of major feedstocks—ethylene, acetylene, chlorine and hydrochloric acid.

As with other petrochemicals such as acrylonitrile, vinyl acetate, and neoprene rubber, the 1960s saw the introduction of new processes which replaced acetylene as a raw material with a less expensive feedstock. Even though the new balanced oxychlorination processes (such as Goodrich, Stauffer and Monsanto processes) have a higher capital cost (see Fig. 6-11) than balanced ethylene/acetylene units of the same size, the raw material advantage of ethylene has been sufficient to more than justify the added capital. At ethylene and acetylene prices of 3 and 8 cents/pound, the switch in feedstocks reduces raw material cost by about 1.1 cents/pound at normal yield ratios. For a 500-million-pound/year plant, the raw material savings for balanced oxychlorination amounts to $5 million/year (90 percent capacity). This in turn is more than enough justification for the approximate $3-$4 million increase in capital cost. While two U.S. vinyl chloride producers (Tenneco and Monochem) have been able to continue operation of highly integrated acetylene complexes, the operation of these units can almost certainly only be justified with an out-of-pocket analysis of cost. No new acetylene-based plants will be built in the United States.

The economics of a 600-million-pound/year balanced oxychlorination producer are shown in Table 6-8. This analysis presents a single year of the life of the plant at 90 percent of capacity, which can be justified as equally accurate with some of the component cost data. In any case, the economics indicate several notable characteristics of the VCM business. First, the two raw materials comprise two-thirds of the 8 percent profited manufacturing cost of VCM. With the large economies of scale in chlorine and the evident trend to oil company domina-

TABLE 6-8—Estimated cost of VCM production by ethylene chlorination and oxychlorination

Component	Usage rate (per lb. VCM)	Input price (¢/unit)	Manufacturing cost (Thousand $/yr.)	Manufacturing cost (¢/lb. VCM)
Chlorine	0.63 lb.	2.25	$ 7,650	1.42
Ethylene	0.47 lb.	3.00	7,600	1.41
Catalyst & chemicals	.....	.....	550	0.10
Steam (net of credit)	1.5 lb.	.05	450	0.08
Fuel	.0018 MM Btu.	25	200	.04
Cooling water	31 gal.	.003	550	.10
Electricity	0.1 KWH	.5	300	.06
2% royalty	.....	.....	500	.09
Total variable costs			$17,800	3.29
Operating labor & supervision			$ 300	....
Maintenance (6% of BL capital)			1,000	....
General overhead (50% of operating & maintenance)			450	....
Taxes insurance and rentals (1½% of fixed capital)			350	....
15% capital charge to earn 8% on fixed investment			3,600	....
8% working capital interest			200	....
Total fixed charges			$ 5,900	1.09
8% profited manufacturing cost (F. O. B., plant)			$23,700	4.38

Basis: Usage rates and capital costs are derived from published claims. See especially Spits, Peter, "Vinyl Chloride Economics," *Chemical Engineering Progress*, 64:3:19-26, March 1968.
600-million-pound/year Gulf Coast plant (F. O. B.)
Working capital = one month of VCM sales value.
Capital cost = 16 on-sites (million dollars)
8 off-sites
24 Total
11 year taxable life
15 year estimated useful life

Note: This is a steady-state calculation for one year at 90% of capacity; a more accurate discounted cash flow might produce a noticably different price. No by-product credits or disposal costs are included: credits for chlorinated solvents feedstocks are assumed to balance heavy and light ends disposal costs.

TABLE 6-9—Sensitivity of VCM manufacturing cost to assumptions

A change in this input	By this amount	Changes cost of VCM by amount (¢/lb.)
Chlorine price	$5/ton	0.16
Ethylene price	0.25 cents/pound	0.12
Energy costs (fuel, steam, electricity)	10 %	0.02
Operating & maintenance costs (without increase in overhead)	10 %	0.03
Construction costs	10 %	0.07

Source: Derived from previous estimate of F. O. B. manufacturing cost.

tion of ethylene production (primarily because of byproduct handling from heavier feedstock cracking), the vinyl chloride business is the obvious domain of both large chlorine producers (Dow, PPG, Goodrich) and large ethylene producers (Conoco, Shell, Dow and Union Carbide). This definite trend should continue for the foreseeable future.

A second notable feature (to the extent that these published data are accurate) is the low profit margin on recent VCM contracts. With the average price of VCM sales (reported by the U.S. Tariff Commission) approaching 4½ cents/pound, it is evident that new VCM plants must be operated very efficiently and with minimal startup difficulties to yield any reasonable return to VCM producers. The sensitivity of a VCM operation to the various manufacturing cost components is presented in Table 6-9. This indicates the probable upward pressure on VCM pricing in the event of increasing costs for fuel, construction, and ethylene which have been characteristic of 1970-1971.

A recent development in VCM manufacture was the announcement of a process to produce VCM directly from ethane, chlorine and hydrochloric acid. The "TRANSCAT" process, as it has been dubbed by its inventors and potential licensors at Armstrong Cork and Lummus, claims to have economics superior to the balanced oxychlorination process. Yields and raw material prices have been reported as superior to oxychlorination and capital costs seem to be comparable. This process presents a potential reduction in manufacturing cost of about 1 cent/pound if these characteristics are present in commercial-sized plants.[14] No announcements of a commercial TRANSCAT venture have been made public to date.

A final, developing factor in VCM economics is the production of 3-5 percent chlorinated byproducts by most oxychlorination processes. While most of these are suitable feedstocks for chlorinated solvents manufacture, a fraction are suitable only for disposal. As environmental laws impinge on the more economic means of disposal—atmospheric venting, deep wells and deep sea dumping—the VCM producers will be forced to more expensive disposal means. These costs will exert an unknown, but potentially significant, upward pressure on VCM price.

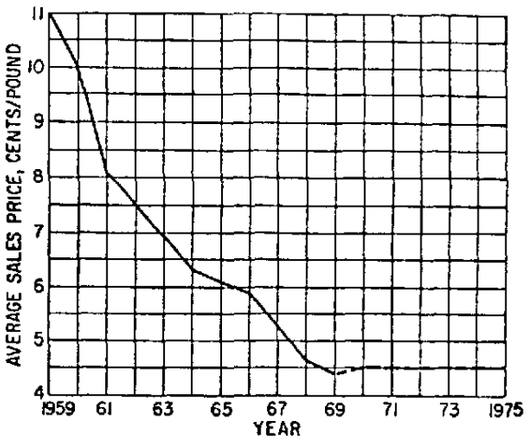

Fig. 6-9—U.S. VCM average selling price, authors' estimates and U.S. Tariff Commission.

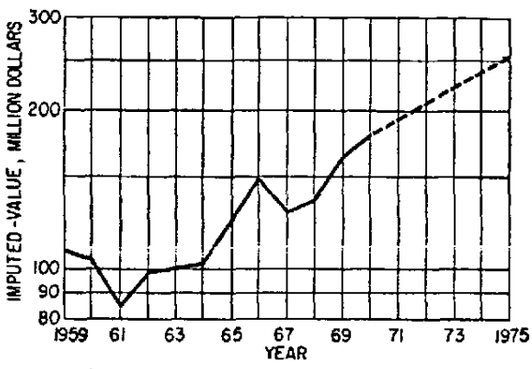

Fig. 6-10—Value of U.S. VCM production, authors' estimates and U.S. Tariff Commission.

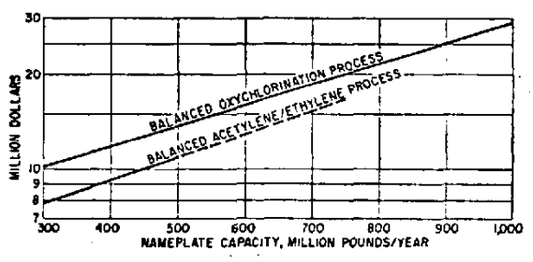

Fig. 6-11—Estimated battery limit capital cost for VCM processes.[14]

THE FUTURE

Despite production volume which indicates approaching maturity in its life cycle, vinyl chloride continues to grow at a rapid rate. This growth has resulted from extension of PVC and copolymers into new materials applications. Replacement of older materials—such as steel and iron in pipe, glass and paper in packaging—will continue to provide the major impetus to PVC and, therefore, VCM growth. While these markets are themselves mature and growing only moderately, their very size allows 15-20 percent annual growth of PVC consumed from only moderate inroads. At the same time, older PVC markets are maturing noticeably and will exhibit growth of 5-8 percent. The upshot will be PVC consumption growth of 10 percent from 1969 to 1975 and

a lower 7 percent growth of VCM production because of a decreasing proportion of exports.

VCM manufacturing costs have been rapidly approaching feedstock values. VCM sells for 4.5-5 cents/pound, ethylene for 3-3¼ cents/pound, and chlorine for 2-2.5 cents/pound in large scale contracts. Therefore, near-balanced oxychlorination is not likely to be supplanted as the major VCM process unless the change to even less expensive feedstocks is involved. Not enough information is available to assess the commercial success of the recently announced TRANSCAT process to convert ethane directly to VCM. If preliminary information is confirmed, watch for TRANSCAT to be employed on a very large scale.

Location of new VCM production will be determined by availability of low-cost hydrocarbons, with VCM transportation by water, pipe line and rail acting as a constraint. If present erosion of U.S. Gulf Coast advantages continues, large VCM markets will draw new producers to the North and East.

The companies which build the next few VCM plants will be those with captive supplies of ethylene, chlorine or both, and those with considerable VCM operating knowhow. Paper-thin profit margins almost preclude entry by any producer that lacks more than one of these three advantages. Look for Dow, PPG and Shell to continue expansion, with Union Carbide and Monsanto considering eventual reentry of VCM production. Introduction of a successful ethane-based process, however, would cause chlorine producers to dominate future production.

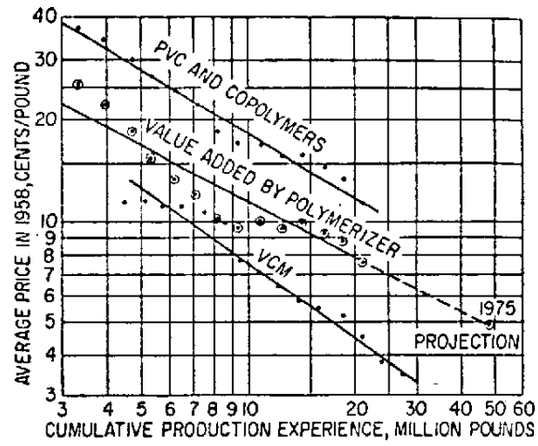

Fig. 6-12—Experience curves for VCM price, PVC price, and value added by polymerizer. Source: U.S. Tariff Commission, Boston Consulting Group, and Manufacturing Chemists Association figures are combined with the GNP deflator (1958 base year) and authors' estimates of future production. A 3 percent inflation projection through 1975 is incorporated.

Based upon these trends (see Figs. 6-4, 6-5 and 6-6) we predict that production of VCM almost exclusively from ethylene will reach 5.6 billion pounds by 1975, with merchant sales at a price of 4.5 cents/pound (1971 dollars). This will result in an imputed value of $252 million for 1975 production (1971 dollars). These large contracts will be written with escalation clauses to offset increasing power and hydrocarbon costs.

Fig. 6-12 presents the history of PVC and VCM pricing, as well as the value added by polymerizers. Projection of the decreasing polymerization margin (using cumulative production experience versus price) gives a further estimate that average 1975 PVC prices will approximate 11 cents/pound (in 1971 dollars).[15]

LITERATURE CITED

[1] *European Chemical News:* Polymer Intermediates, Oct. 30, 1970, p. 5.
[2] *Hydrocarbon Processing*, November 1967, p. 239; *Chemical Week*, Aug. 29, 1964.
[3] "Foreign Aid for Vinyl," *Chemical Week*, Sept. 24, 1966.
[4] *Hydrocarbon Processing*, November 1969, p. 249.
[5] *Hydrocarbon Processing*, November 1969, p. 248.
[6] *European Chemical News*, April 30, 1971, and *Oil and Gas Journal*, Nov. 8, 1971.
[7] *Chemical Engineering*, April 22, 1968, pp. 142-144.
[8] Freiling, Huson and Summerville, "Which Feedstock for Ethylene," *Hydrocarbon Processing*, November 1968, p. 149.
[9] Faith, Keyes and Clark, *Industrial Chemicals*, Wiley, 3rd edition, 1965, p. 809.
[10] "Polyvinyl Chloride: Outlook and Opportunities," John Auchter (B. G. Goodrich), Chemical Marketing Research Association, New York, May 6, 1971.
[11] *Chemical Week*, Aug. 18, 1971, p. 26.
[12] *Chemical Week*, May 24, 1969, p. 32.
[13] *Oil, Paint and Drug Reporter*, May 5, 1969, p. 3.
[14] *The Oil and Gas Journal*, March 8, 1971, p. 53.
[15] For an explanation of the experience curve method of price forecasting, see the various publications of the Boston Consulting Group, including, "Perspectives on Experience," Boston, 1968.
[16] "Vinyl Chloride Economics," Peter Spitz, *Chemical Engineering Progress*, March 1968, p. 19-26 with appropriate escalation factors to 1971 applied by author.

END OF SERIES

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