Feb, 73

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

David P Keane Robert B Stobaugh and **Phillip L Townsend** Harvard University Graduate School of Business Administration Boston Mass

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 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)O 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

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

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

$$CH = CH + Cl \longrightarrow CH\ Cl - CH\ Cl$$

Ethylene Chlorine Ethylene dichloride (EDC)

$$CH\ Cl - CH\ Cl \xrightarrow{900\text{-}950\ F} CH_2 = CH\ Cl + H\ Cl$$

EDC VCM Hydrochloric acid

$$HC \equiv CH + H\ Cl \longrightarrow CH_2 = CHCl$$

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

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

Ethylene Chlorine EDC

Oxychlorination

$$CH_2 = CH_2 + HCl + {}_2O_2 \rightarrow CH\ Cl - CH_2Cl + H_2O$$

Ethylene EDC Water

Cracking

$$CH\ Cl—CH_2Cl \xrightarrow{900\text{-}950\ F} CH_2 = CHCl + HCl$$

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

$$2\ HCl + {}_2O \longrightarrow Cl_2 + H\ O$$

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

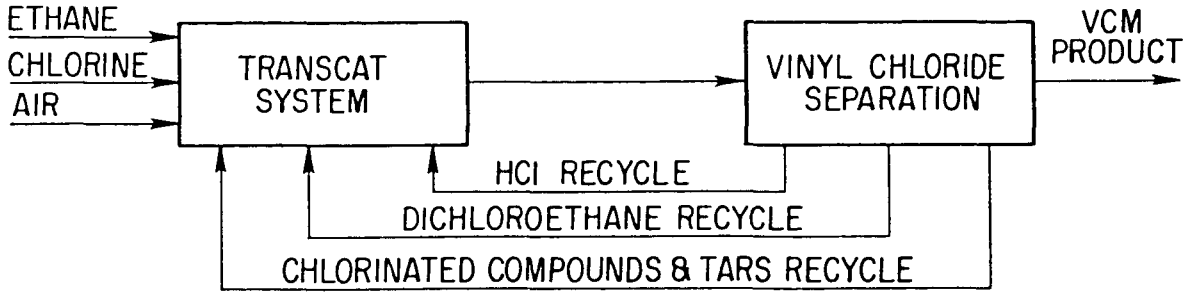


Fig 1—Vinyl chloride monomer process via ethane as offered by Lummus/Armstrong

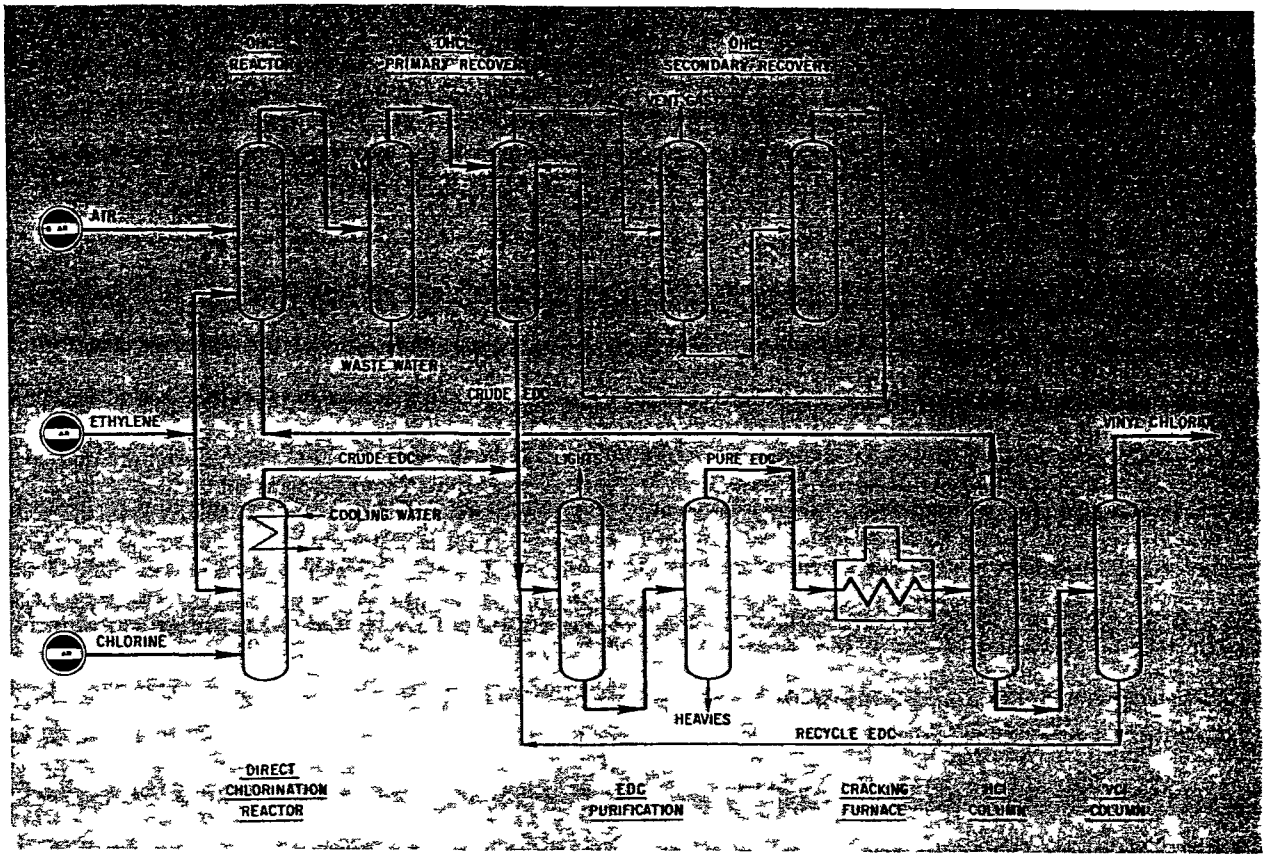


Fig 6 2—Vinyl chloride by oxychlorination by B F Goodrich

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

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

Ethane Ethylene

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

Ethylene Chlorine EDC

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

EDC VCM Hydrochloric acid

$$2\,HCl + \tfrac{1}{2}\,O \xrightarrow{\text{molten salt}} Cl + H\,O$$

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

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 and C 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 stoichio metric in both reactants with chlorine usually maintained in a slight excess The reaction is liquid phase with a dissolved catalyst and mildly exothermic Reactor tem perature 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)

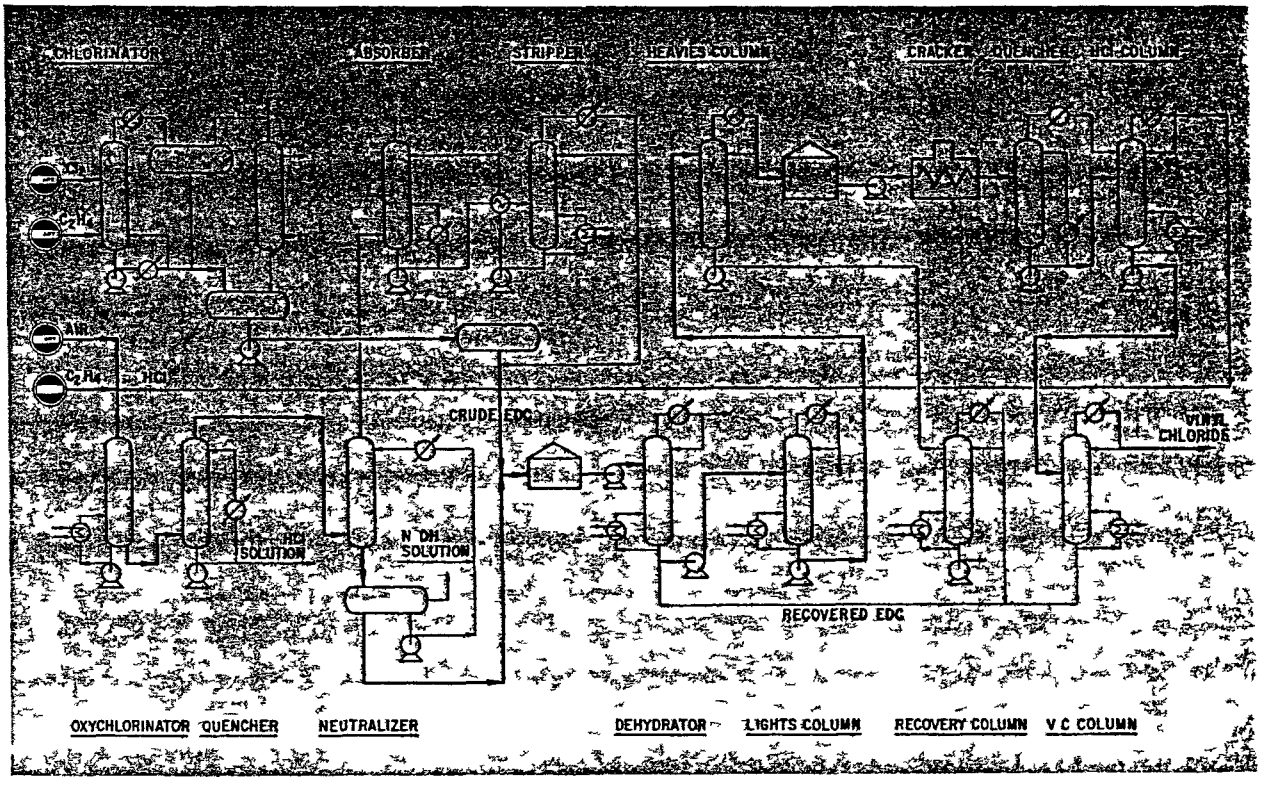
The second major operation consists of cracking EDC to produce vinyl chloride and anhydrous hydrochloric acid The cracking occurs at 900 1 000 F in a direct fired furnace which is packed with a catalyst (pumice has been a traditional choice) Conversion of EDC is typically in the 50 60 percent range to 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 prod uct meeting finished product specifications and produces a recycle EDC stream of unconverted EDC This stream is purified in the common EDC columns prior to recycl ing 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 condensa tion 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 absorp tion/stripping The tail gases are vented while crude EDC is fed to the common EDC finishing train

The oxidation of HCl to Cl is highly exothermic and the subsequent addition of Cl to ethylene is mildly exo-thermic 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 con version 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 pro cess very similar to that of B F Goodrich has been employed in several Japanese plants The essential de sign differences appear to be (1) the use of a fixed bed reactor for oxychlorination as opposed to the B F Good rich 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



F g 6 3—Toyo Soda s oxychlorination vinyl chloride process

major the processes should be oughly competitive based upon published data [3]

3 Stauffer Chemical oxychlorination This is again very similar to the earlier oxychlor nation 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 Monsanto oxychlorination There are several licen sees for this similar process

5 Dow oxychlorination Only Dow and foreign sub sidiaries have used the Dow VCM process and no indi cation 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 Car bide 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 /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 pro cess

Diamond Shamrock/deNora offer Dianor a process to produce and crack EDC which is aimed at developing countries with no ethylene complexes The process op erates on ethylene as low as 60 percent concentration and produces HCl byproduct which would leave the process uncompetitive under any but the special circum stances 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 Econom ics) Future manufacturing efforts will be largely influ

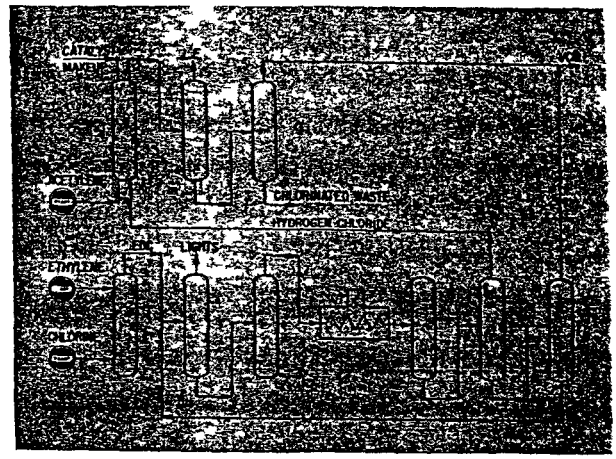


Fig 6-4—Author s interpretation of the balanced VCM process as announced by Union Carbide (Lummus)

TABLE 6 1—P p rties f VCM

M l wt.	62 50	
Specifi gravity	0 9834	20°/20 C
Melti g point	−153 8 C	(−244 6 F)
B l g point	− 13 81 C	(7 1 F)
Flash point	−108° F	
Maxim m allowabl co cen rat (ppm by ol m)	500	
E plos limit % by l m	L w 4	
	Upper 22	

enced by trends in both of these related fields A brief review of trends follows

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 Some recent plants have involved movement toward the north and Puerto Rico and cracking of heavy feedstocks With developing short ages of natural gas a continuing erosion of the competi tive 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 produc tion 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 pro-duction 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 There fore 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 r lative labor and constr.ction costs water and transpor tation 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 Con sumption 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 produc tion experienced in 1970 to the more usual level of 5 6 percent of production or 300 million pounds by 1975

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 As a result PVC con sumption is also less vulnerable to the loss of any single end use market

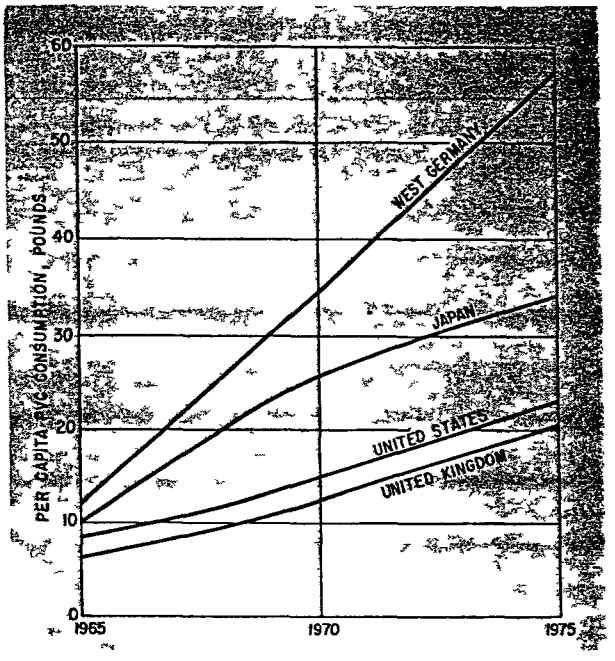


Fig 6 5—Per capita consumption of polyvinyl chloride

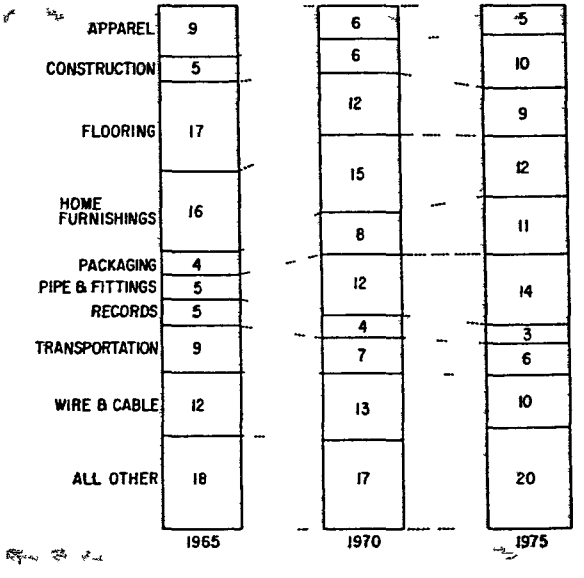


Fig 6 6—End use markets for PVC

The more rapidly growing markets for PVC are con struction 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 trans portation 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 ac tual volume sold in 1975 is projected to increase in all categories

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 how ever 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 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 rela tively high growth rate Further penetration of the auto mobile market is not a major hope for PVC since seat

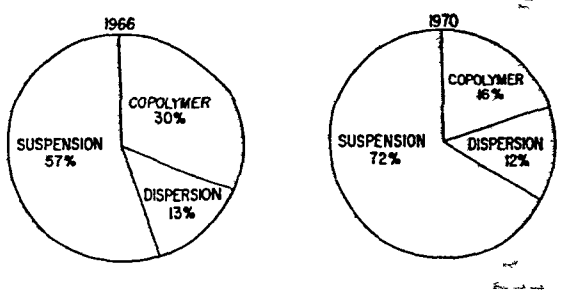


Fig 6 7—PVC production by type according to the U S Tariff Commission

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—P i g meth d f PVC[39]

	Sh f m k %
E (w film hee d ral ex ru) C lend rin (film heet and coa)	40
M ld g (bl w injecti t mp ss)	35
C t g (d k f ll ra lam ti)	10
Oth	10 5

TABLE 6 3—PVC p d ers in the U ited States Jan 1 1971

N hea t B den D m d Sh m ock	L m t M ss	12 mpa
F re t B F Goodri h Ch m cal	D l w re C y Del P tt n, P	13 pl 1 300 MM lb cap city
Goodyea T re & R bbe	P d k wn N J	
Great Am rica Pl stics	N g ra Fall N Y	
Hooker M sant Ol P sot	F hb M ss B l g N J Sp gfi ld M ss Ass t M P sa N J	
Sta ff T eco	Del wa C y D l B l g N J Fl m N J	
So hea A Prod cts C t ental O l F re P so U C b d	P col Fla Abe deen M ss P y ll Md P t Pl sa W V S Charl W V	5 mp ies 5 plant 450 MM lb cap ty
Midw A P od t All d Ch m cal B d Ge eral T re B F Good h Ch m cal	C l rt C ty Ky P ll Oh Ill p l Ill A htab la Oh H y Ill A L k Oh L ll K P ill Oh	6 mp es 8 pl 1 000 MM lb cap ty
U yal S u hwes D m d Sh m ock E hyl Goody T & R bbe U C b d	Dee P k Texa B R L Pl q m L T xa C T	4 mp 4 pl 600 MM lb cap ty
F Wes Am ca Ch m cal B F Goodri h Ch m cal K yso	L g B h C l f L g B h C l f Sa C l f	3 mp 3 pla t 200 MM lb cap ty
		21 l mp nies 33 l pl n 3 550 MM lb l p ity

TABLE 6 4—W t E pea PVC umpti n (th d f m t i t n)

Yea	EEC	EFTA	Sp i	O h	T tal W ern Eu pe
1972	506	227	17	40	795
1963	610	255	26	52	943
1964	69	308	29	72	1 178
1965	843	339	33	56	1 271
1966	950	359	46	55	1 410
1967	1 061	401	59	141	1 661
1968	1 22	472	71	155	1 925
1969	1 505	525	91	140	2 261
1970	1 598	557	97	148	2 400
G w h t 1962-1970)	15%	12%	24%	18%	15%
1975 C m	2 575	820	220	285	3 900
P d g w h R (1975)	10%	8%	18%	14%	10%

S E p n Ch mi l N w d Oil P i d D g R p O 26 1970 l h m

rapidly expanding domestic markets for PVC and the high relative freight costs Furthermore tariff barriers are h gh—20 percent or more—between European coun tries 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 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 ex ports 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 com petitive 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

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 oxychlorina tion capability These plants must be considered vulner able to continued construction of large oxychlorination facilities The remaining 5 billion pounds (82 percent) consists of modern apparently competitive oxychlorina tion 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 Louis iana

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 capac ty construct on has been even more

TABLE 6 5—U S p du ers f VCM

P d	Loca i	N m pl pacity (MM lb /yr)	P ocess
All ed American Ch m cal (ARCO St ff)	B R L	300	O hlori
	W tso Cal f	170	St fier y hl t
M och m (B d U yal)	Ge mar L	300	Acetyl
C oco	L k Ch les L	600	S ff ychl in t
D w	Pl q m L	340	D w chl
	F eeport Texa	180	Dow y hl rn t
	Oy Creek T xa	700	D w y hl rn t
E hyl	B R g L	270	Ethylen /EDC cra kin
	H t	150	E hylen /EDC kin
G od h	C l rt C y K	1 000	Good h y hl t (m l pl ra)
PPG	L k Chari L	300	O y hl ri ti
	P rt R	500	Oxy hl ri t
Sh ll	H	800 (E d g)	S ff y hl rn t
	N rc L	800 (1974)	S ff y hl rnat
T ec	H st	255	Ace yl
	1972 T tal	5 865	

So M p bl h d e m t rpre d by th h rs N h ff t p ci y p b bly doe q al m pl p ty A so bl p y fig w ld p b bly be 90% f h bo ra *Oil P nt d Dr R ports* O 11 1971 h th m t mpl l

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

Among individual companies Dow has about 19 per cent of VCM capacity and about 23 percent of oxy chlorination capacity Dow s position as a capacity leader among ethylene chlorine and chlorinated solvents pro-ducers 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 Econom cs) In addit on byproduct chlorinated hydrocarbons from oxychlorination are rou tinely absorbed into Dow s production of perchloro ethylene and carbon tetrachloride At the present time this VCM is largely sold in the merchant market While Dow has extensive experience n production of bulk poly mers 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 Man ufacture) 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 Cal vert 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 bus ness 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 com panies with large ethylene capacity but insuffic ent chlorine for VCM production Shell has recently com pleted and started up 12 14 percent of U S industry

TABLE 6 6—Foreign VCM producers

Co try	Comp y	City	An u l capacity (h sa d m ri n)	P ocess/ mpl ti n
EUROPE				
B lg m	BASF	A werp	120	Sta fi
	Solvi	J m ppe	200	Sol y—ICI
	L mb gse V yl	T sse d loo	200	Goodri h
Czechosl vaki	Tech oe p rt	N vaky	50	Good h/Hoe h t
¯l l d	P k m O	P ¬voo	53	Solva /ICI
Fra	DAUFAC		90	E hyl (exp d g)
	P h y S t G b	L Vera	120	Own (1972)
			120	Eth l b sed (1972)
	S lvay	T va	200	B l ced cetyl / hyl
G eece	E hyl H ll		25	E h l EDC ra kin
Italy	ANIC	R en t	250	Sta ffer (compl)?
	M d so	P rt M h ra	250	Good ch
			180	(1971)
	R m ca	C gli ri	100 (expanded)	PPG (1972)
N th l nd	AKZO	B tl k	300	Goodri h/Sta ff
	Sh ll	P rn	75	
R m ni	I d ial Imp	R m co V ice	36	N A
Spain	M sa Iber ca	Tarrag	50	M sa /E hyl
	Oxycr	P ert ll	80 (pl ed)	Goodri h
	V cl	M rt rell	55	Sol y/ICI (1972)
Sw d n	K m d	geu d	75	E hyl
U K	B P Ch m cal	B la B y Wal	260	Good ch
	B h Ge		140	Acet l
	ICI	H llh se	N A	O y hl ri ti
USSR	Techm h mport	R rn	N A.	Ox hl ri ti
		D erj k	30	P-S-G (1972?)
W t G m y	BASF	Go k	33	Sta ff (1973?)
	Ch mW i H l		300	Bal ced
	Hoech	Marl	365 (expa d d)	H l (1972)
	K psa k AG	Kn psa k	60 (plan ed)	Good h/Hoech
	W i Ch m	K l	100	Goodri h/Hoech
		B rgh sen	N A.	Ace ylen (1971)
LATIN AMERICA				
Arg l	El ocl SAIC	C p t B rm dez	o0 (pl ed)	ICI (1973)
	l d tri s-D w	B h Bl ca	50 (pla ed)	Dow (1974)
Bra il	C so P l	Elcl	100	E hyl/Sol y/ICI
		S P l	100	Sol /ICI
	U C b d	N A.	85	B l ced ethyl -a tyl
				(1972)
Chil	Emp sa N l d P l	C cepc	15 (pl)	N A
	P m D w ENAP	C cepci	15 (plan)	D w
M i	PEMEX	P ra oe	70	Sc fi Design
V l	B F Good h/IVP/ hers	El T bl	50	B F Good ch (1973)
AFRICA/MIDDLE EAST				
Egypt	Ge 1O f l d t y	Alex dri	43 (pla d)	N A
T k y	P k m P k my	I m	30	S l /ICI
		Al	95 (pl d)	1974
		Y rimca	27 (pl d p)	1972
ASIA/PACIFIC				
Au trali	Good h	Al	N A	Goodri h
J p n	Asah P Ch m cal	Go	145 (EDC)	PPG
	C tral Ch m	K wasak	90 (EDC)	T y Sod
	Ch b VCM	Ch b	160	Sta ff
	Ch sso P -ch m l	M m t	55	T y S d (1972)
	J pa ese Ge		130	B la ced Goodri h
	K f h	Osak	120	S ff
	K M h m	M h m	50	M sa /Sc fi D g
	K h		120	B l ced
	M b h M sa	Y kk h		M su
	M t	N g y	60	Sc t fi D g
	M T t	Iwak	N A	S fi
	N h VCM	N h	80	M
	Se k P -ch m l	Osak	120	T y Sod
	T Sod	T k m	110	T Sod
		Y kk h	100	D w
K ea	K P fi Ch m l	Ulsa	60	M sa /T k y m
T iw n	Ch P t l m	K h g	64	U C b d (1972)
	T wa VCM	T f	60 (pl d)	Dyn m N bel
Th il d	Th Pl t	B k k	40	

So ce A h rs m b sed m y p bl h d rce Th l t d d b mp h b t l m t m j od cers

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

TABLE 6 7—U S hi t l al d ta VCM, 1959 to 1975

Yea	Numbe f p odu	P od i n MM lb /yr	S les MM lb /yr	A rag p i ¢/lb	T tal valu f p od 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	3 736	2 356	4 4	164
1970	9	4 000	2 520	4 5	180
1975	10	5 600	4 200	4 5	252

S US T ff C mm
A th m w h p ce p ; t 1971 d ll

HISTORICAL DATA

Table 6 7 presents data based on U S Tariff Commiss on 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

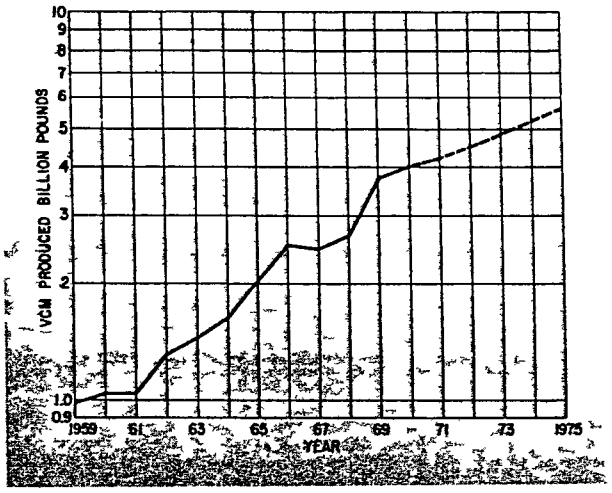


Fig 6 8—VCM production in the United States U S Tariff Commission and authors estimates

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

Comp	U g ra (pe lb VCM)	I p i (¢/ l)	M f ing os (Th d $/yr)	(¢/lb VCM)
Chl	0 63 lb	2 25	$ 650	1 42
E hyl	0 47 lb	3 00	600	1 41
C taly & h m l			550	0 10
S m (f d)	1 5 lb	05	450	0 08
F el	0018 MM B	25	200	04
C l g	31 l	003	550	10
El	0 1 KWH	5	300	06
2% l			500	09
T l bl			$1 800	3 29
Ope g l bo &			$ 300	
M (6% f BL tal)			1 000	
G l h d (50% f & m ce)			450	
T d l (1½% f fi d l)			350	
15% p l h 8% fi d m			3 600	
8% w k g p l			200	
T l fi d h			$ 5 900	1 09
8% fi d m f (F O B pl)			$23 00	4 38

B U d p l d d f m p bl h d l m See p ll Sp P V yl Chl d Ec m Ch l E g g P g
64 3 19 26 M h 1968
600 m ll p d/ G lf C l (F O B)
W k l = m h f VCM sal l
C p l = 16 (m ll d ll)
8 ff
24 T l
11 bl l f
15 m d sef l l f
N Th d l l f 90% f pa m d d h fl w m h od bl d fi ce N by
od d d posal l d d ed f hl d l feed ock m d b l h d l h d d l

TABLE 6 9—S itivity f VCM ma fa tu g t t a mpt n

A h ng in hi l pu	By hi m u	Ch g oe f VCM by m n (¢/lb)
Chl rin price	$5/t	0 16
Ethyl price	0 25 ce /p d	0 12
E ergy cost (f el steam el city)	10 %	0 02
Operating & m t ce ts (with t ease n h d)	10 %	0 02
C stru t sts	10 %	0 07

S ce Der ved f m pre t m t f F O B ma f t g ost.

tion of ethylene production (primarily because of byprod uct 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 Car bide) This definite trend should continue for the fore seeable 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) ap proaching 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 super or to the bal anced 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 No announcements of a commercial TRANSCAT venture have been made public to date

A final de elop ng factor in VCM econom cs is the production of 3 5 percent chlorinated byproducts by most oxychlorination processes While most of these are suit able 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

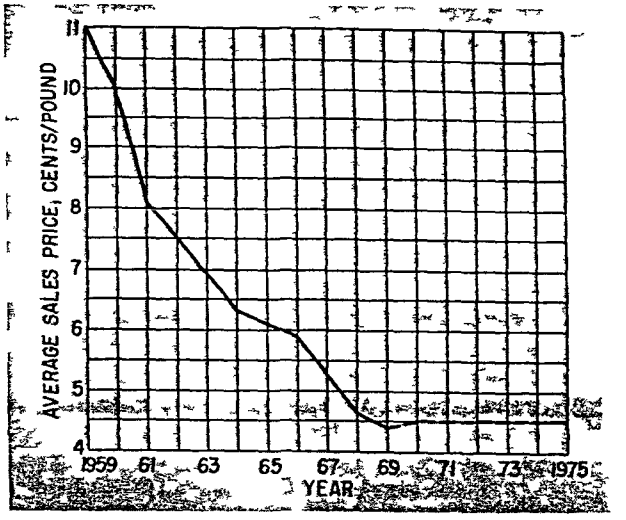


Fig 6 9—U S VCM average selling price authors estimates and U S Tariff Commission

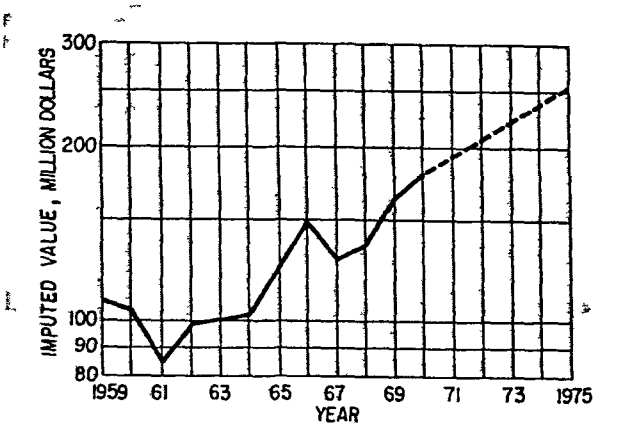


Fig 6 10—Value of U S VCM production authors est mates and U S Tariff Comm ssion

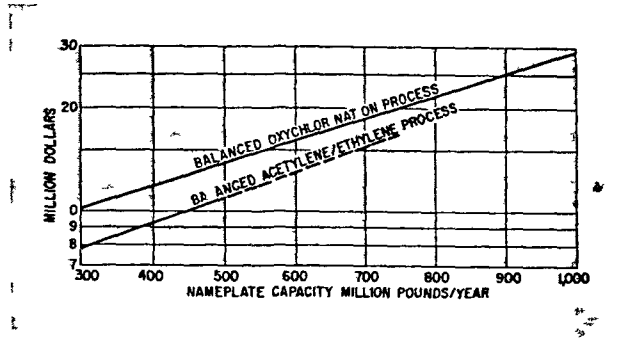


Fig 6 11—Estimated battery limit capital cost for VCM pro cesses

THE FUTURE

Despite production volume which indicates approach ing 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 them selves mature and growing only moderately their very size allows 15 20 percent annual growth of PVC con sumed 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 3/4 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

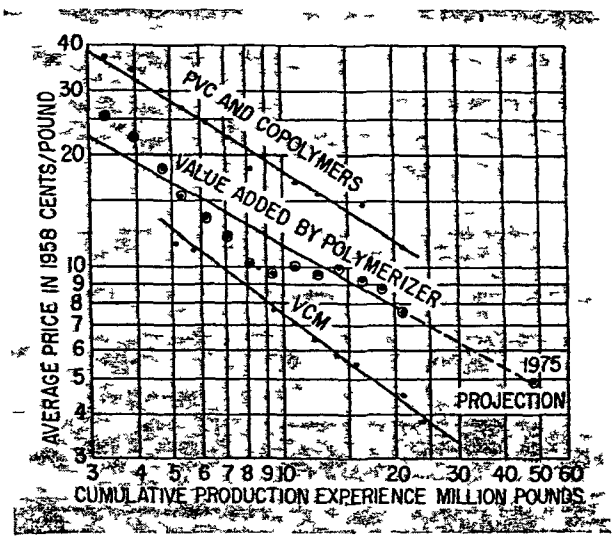


Fig 6 12—Experience curves for VCM price PVC price and value added by polymerizer Source U S Tariff Commission Boston Consulting Group and Manufacturing Chemists Association figures are combined with the GNP deflator (1958 base year) and authors estimates of future production A 3 percent inflation projection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

LITERATURE CITED

E p Ch m al N w P l m l rm ch es O 30 1970 p 5
Hyd b P g N mbe 1967 p 239 Ch m al W k A g 29 1964
F gn Aid f V yl Ch m al W k S p 24 1966
Hyd b P g N mbe 1969 p 249
Hyd b P g N mb 1969 p 248
E p Ch m al N w April 30 1971 d Oil d Gas J al N 8 1971
Ch m al E g April 22 1968 pp 142 144
F l g Hus d S mm rv ll , Wh h F d k f E hyl H d b P g N mbe 1968 p 149
Faith K ye d Clark I dus al Ch m al W l y 3 d di 1965 p 809
P lyv l Chl d O look d Opp tu es J h A ch (B G G d h) Ch m cal Mark g R ch Asso N w Y k M y 6 1971
Ch m al W k A g 18 1971 p 26
Ch m l W k M y 24 1969 p 32
Oil P d D g R p M y 5 1969 p 3
Th Oil d Gas J al M h 8 1971 p 53
F pl f h p urv m h d f p f cas g, th ar us p bl ns f h Bos C l g G p cl di g P p Exp n B 1968
V yl Chl d E m cs P Sp tz Ch m l E g g P g Mar h 1968 p 19 26 w th pp p cal f rs 1971 ppl d by th

END OF SERIES

About the authors

DAVID P KEANE is a p duct manage ment x cutive n the Friden D vision of the S nge C He rece ved an M B A from Harvard Bus ness School in 1970 He also h lds an A B in economics f om G o get wn Uni e sity Wash ng ton D C and th Ce tifi at f m the Un v sity of Frib u g Swit er land n F nch l t atu

ROBERT B STOBAUGH s a p f s r at Harvard Busin s S ho l where he teaches a doct al sem nar n interna tional technology and pr ducti n He holds a B S n hem cal eng n ring f om L u siana St t University and a recent doctorate from Harvard Busi ness Sch l He has served as a c n sultant to a number of chemical and oil firms and g vernments and has en gineering experience with Monsanto Caltex O l Group and Jersey Standard affiliates He has written nume ous arti les and two books Petrochem cal Manufacturing and Marketing Guide Volume I and II (Gulf Publishing Co)

PHILLIP TOWNSEND is an industrial consultant and w king t wa d a doctorate at Ha vard Bus n ss Sch ol His spe c al field is production and operati ns management particularly in petro chem cals He has held techn al and managerial pos t ns with W R G ace A nerican Oil and Shell Chemical Mr Townsend eceived a B S in econom cs and chemical eng ne ring from M I T and an M S in chemical engineering from Pu du