RESEARCH COUNCIL OF ALBERTA

Information Series No. 39

Proceedings of Symposium

on

ALBERTA PETROCHEMICAL INDUSTRY

held in

Northern Alberta Jubilee Auditorium, Edmonton, Alberta
March 14 and 15, 1962

Price $2.00

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PROCEEDINGS OF SYMPOSIUM

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ALBERTA PETROCHEMICAL INDUSTRY

Sponsored by
Chemical Institute of Canada, Edmonton Section
and
Research Council of Alberta

Northern Alberta Jubilee Auditorium, Edmonton, Alberta
March 14 and 15, 1962

Research Council of Alberta
87th Avenue and 114th Street
Edmonton, Alberta
1962

FOREWORD

The abundant availability of liquid and gaseous hydrocarbons in Alberta together with favorable economic factors have led to the development of a substantial petrochemical industry in Alberta. To illuminate and assess the various pertinent factors upon which further petrochemical development will be based an Alberta Petrochemical Industry Symposium was sponsored by the Chemical Institute of Canada, Edmonton section and the Research Council of Alberta on March 14 and 15, 1962 at the Jubilee Auditorium, Edmonton, Alberta.

The papers covered a wide range of topics including raw material reserves, history of the petrochemical industry in Alberta, a series of papers on the technical aspects of petrochemical manufacture, latest trends in a number of areas and pertinent economic considerations. The excellent material and presentations by top most representatives from the many fields made the symposium an outstanding success.

The success of the symposium is a tribute to the fine spirit of co-operation of the many participating bodies - the Chemical Institute of Canada, Edmonton section; the University of Alberta; the Research Council of Alberta; and the Department of Industry and Development. The Jubilee Auditorium provided a most fitting locale for the program.

A special acknowledgement is extended to the Research Council of Alberta for bearing the major expenses in the publishing of these Proceedings.

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FUEL AND RAW MATERIALS FOR THE PETROCHEMICAL INDUSTRY IN ALBERTA

G. W. Govier
Dean of Engineering and Deputy Chairman, Alberta Oil
and Gas Conservation Board

Dr. Govier, born in Nanton, Alberta, received his secondary school education in Vancouver, British Columbia, and attended the Universities of British Columbia, Alberta, and Michigan, receiving the degrees of B.A.Sc. (Chemical Engineering) in 1939, M.Sc. (Physical Chemistry) in 1945, and Sc.D. (Chemical Engineering) in 1949. He has been on the staff of the University of Alberta since 1940 and is at present Dean of the Faculty of Engineering. Dr. Govier has served as a member of the Oil and Gas Conservation Board since 1959. He is a member of the Chemical Institute of Canada, the Engineering Institute of Canada, the Canadian Institute of Mining and Metallurgy, the American Institute of Chemical Engineers, and the Association of Professional Engineers of Alberta of which he was President in 1958-59.

It is a pleasure for me as representative of the Oil and Gas Conservation Board to open the symposium on the Petrochemical Industry in Alberta by discussing the fuel and raw material situation. Alberta has been endowed with a plentiful supply of natural gas, crude oil and condensate, the main sources of hydrocarbons for use both as fuel and as raw materials for the petrochemical industry. These hydrocarbons are already being used in a number of important chemical operations in Alberta, and will be used in many more in the future.

It is my intention to deal primarily with the hydrocarbons derived from natural gas since, in Alberta, these are of much greater importance in the petrochemical industry than those derived from crude oil. I will, however, make brief reference to the light hydrocarbons produced as a by-product of crude oil refining.

I understand that many in this audience are not too familiar with the gas business. For this reason, I will start out with a brief discussion on the nature and composition of gas to set the stage for a consideration of the reserves and availability of fuel gas and raw materials.

Natural Gas

First, what is natural gas and where does it come from? Natural gas is a complex mixture of the lower paraffinic hydrocarbons, consisting mainly of methane, with varying amounts of ethane, propane, iso-butane, n-butane, iso-pentane, n-pentane, and traces of higher hydrocarbons along with various contaminants. The main contaminants are hydrogen sulphide, carbon dioxide and nitrogen.

Gas may be found in contact with crude oil or alone in a reservoir. Gas found in contact with crude oil is normally classified as "associated" gas while gas found alone is termed "non-associated" gas. The term associated gas refers both to gas cap gas found directly overlying crude oil accumulations and to solution gas which is dissolved in the crude oil and is unavoidably evolved upon production of the oil.

In all natural gases the proportions of the hydrocarbon constituents decrease with increases in molecular weight, but there is a tremendous range in gas compositions, both with respect to the hydrocarbons and the various impurities. Gases which are high in methane and low in propane and higher components are commonly known as "dry gases". Gases which contain commercially recoverable quantities of propane and higher hydrocarbons are called "wet gases". Gases which are free of hydrogen sulphide are termed "sweet"; those containing hydrogen sulphide are "sour".

Solution gas which is produced in conjunction with oil production is invariably of a wet variety and is an important source of raw materials for the petrochemical industry. The gas cap gas is usually or a composition intermediate between non-associated dry gas and wet solution gas. Another intermediate grade of gas is that produced from what are known as condensate reservoirs. In this type of reservoir the hydrocarbons actually occur in the reservoir in a single phase near the critical temperature and pressure. Reduction of pressure accompanying production from such reservoirs causes retrograde condensation and results in production at the surface of a condensate, and a condensate gas which is usually relatively dry.

In summary then, natural gas of widely varying composition may be produced from dry gas fields, wet gas fields, solution in oil fields, gas caps in oil fields and from condensate reservoirs. The composition of four typical gases is indicated in Table I. The Medicine Hat gas, whose composition is shown in column two of the table, is a typical non-associated gas and a typical dry and sweet gas (it does not contain significant quantities of the higher hydrocarbons or hydrogen sulphide). The Judy Creek gas, whose composition is presented in column three is a typical wet and sweet solution gas. The Redwater gas, whose composition is given in column four, is a wet and sour solution gas. Column five presents the composition of a typical condensate type gas (Windfall). This gas is intermediate with respect to liquid content and is sour.

TABLE I. ANALYSES OF TYPICAL RAW NATURAL GASES

(1)	(2)	(3)	(4)	(5)
Field	Medicine Hat	Judy Creek	Redwater	Windfall
Zone	Medicine Hat Sandstone	Beaverhill Lake	Leduc	Leduc
Type	Dry Sweet Gas	Wet, Sweet Solution Gas	Wet, Sour Solution Gas	Condensate Gas
Component	Mole %	Mole %	Mole %	Mole %
Methane	95.62	61.95	48.72	63.57
Ethane	0.24	17.21	18.86	4.18
Propane	0.05	11.25	15.65	2.50
Iso-Butane	0.02	1.10	2.35	0.62
N-Butane	0.03	2.65	4.53	1.40
Pentanes Plus	0.03	1.29	2.68	6.67
Hydrogen Sulphide	0.00	0.00	3.45	15.41
Carbon Dioxide	0.00	1.70	3.76	4.15
Nitrogen	3.72	3.21	-	1.50
Helium	0.29	-	-	-
	100.00	100.00	100.00	100.00
GPM (1)				
Propane	0.0114	0.571	3.576	0.571
Butanes	0.0132	0.993	1.822	0.535
Pentanes Plus	0.0102	0.440	0.913	2.273

(1) Imperial Gallons per MSCF as sampled (14.65 psia, 60°F)

Processing of Gas

All natural gases except those which are dry and sweet require processing. This processing is necessary to make the gas transportable and marketable, and in many cases it is carried out also for the recovery for separate use or sale of the economically recoverable natural gas liquids (propane, butanes and pentanes plus) or sulphur. Occasionally the gas is processed for the recovery and separate sale of ethane.

To meet normal specifications in the case of a wet gas, in addition to acid gas removal if the gas is sour, virtually all of the pentanes and heavier hydrocarbons and some of the butanes and propane depending on the remaining composition of the gas, must be removed. The actual degree of removal of the propane and butanes depends to a great extent upon the economics of marketing these particular products. If marketing conditions warrant some ethane might also be removed from the gas at these processing plants.

The processing normally takes place at plants located in the fields where the gas is produced. As a result the pipe lines carrying residue gas to marketing centers carry specification fuel gas which is mainly methane but which usually includes virtually all of the ethane originally contained in the gas and in many cases a considerable proportion of the original propane and butanes.

The propane and butanes recovered from the gas are available at the field plants. For this reason the location of the gas processing plants is of interest to the petrochemical industry. Figures 1 and 2 show the location of the main gas processing plants now in operation in Alberta and some of those expected to be built in the near future. Figure 1 presents those plants serving local markets, while Figure 2 presents the plants that are serving primarily extraprovincial markets.

Natural Gas Reserves

The reserves of natural gas and the associated natural gas liquids are of utmost importance to the petrochemical industry. Natural gas reserves can only be estimated, and the accuracy of the estimates depends on the accuracy of the data available on the underground reservoir. Gas reserves are estimated by two general methods, the volumetric method and the pressure-decline method. The volumetric method is based on an estimate of areal extent, porosity and thickness of the underground reservoir; the pressure, temperature, and compressibility factor of the gas; and the recovery factor.

The pressure decline method consists of plotting the pressure of the reservoir (suitably corrected for the changing compressibility factor) versus the gas production, and extrapolating the plot to a reasonable abandonment pressure. The method is a valuable one provided there has been sufficient production history and that there is no water encroachment into the reservoir and the gas is being withdrawn from a constant volume space.

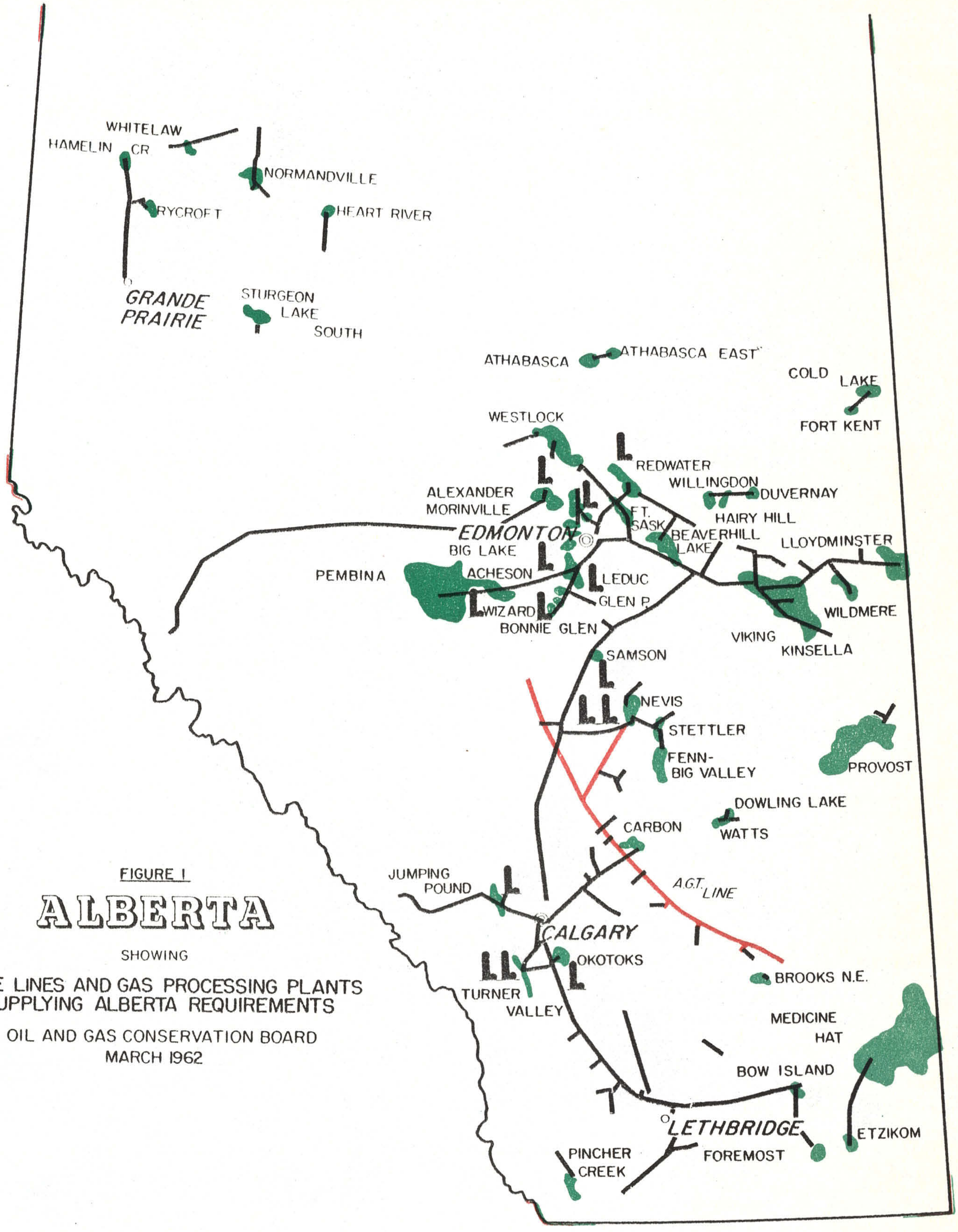

FIGURE I

ALBERTA

SHOWING

PIPE LINES AND GAS PROCESSING PLANTS SUPPLYING ALBERTA REQUIREMENTS

OIL AND GAS CONSERVATION BOARD
MARCH 1962

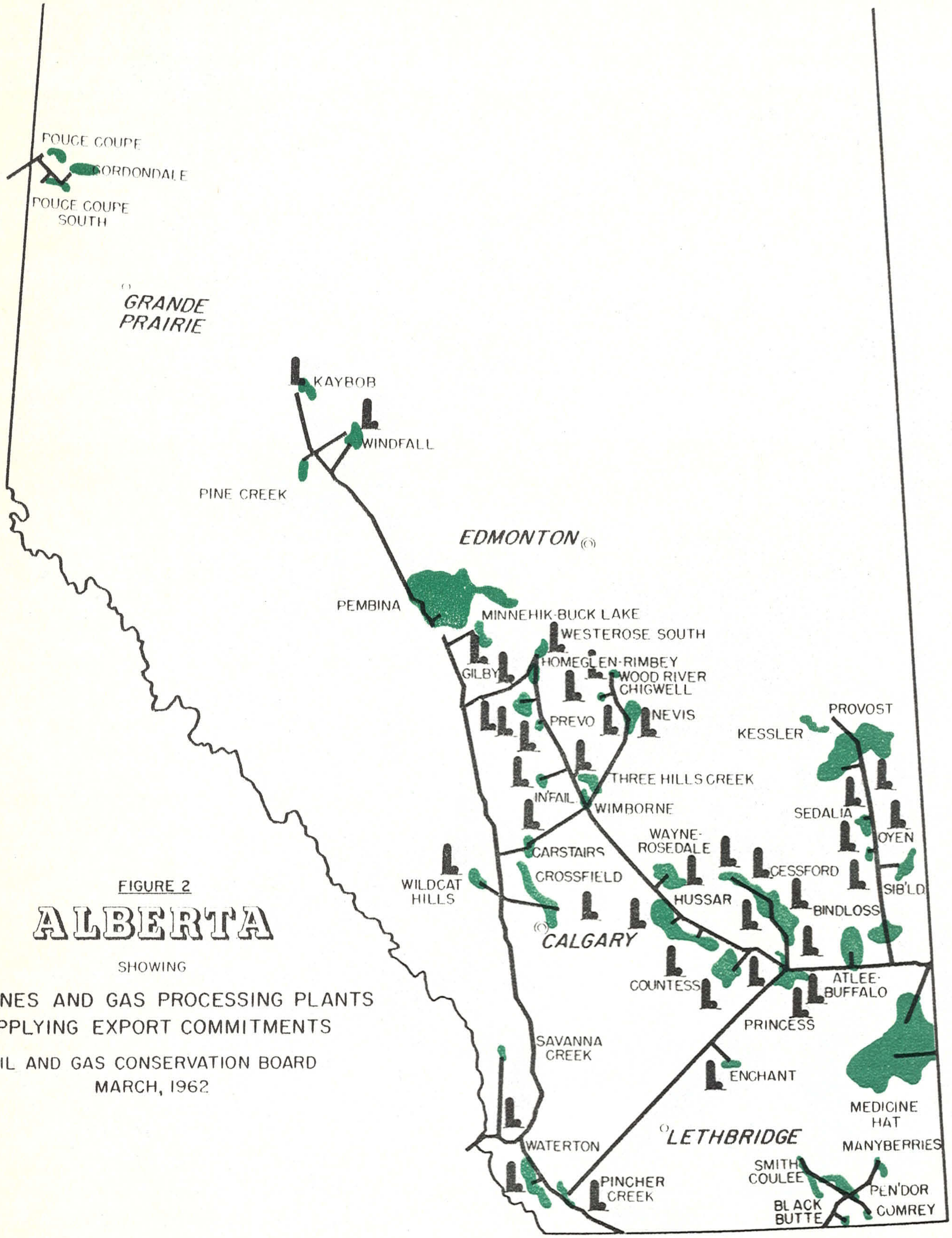

FIGURE 2

ALBERTA

SHOWING

PIPELINES AND GAS PROCESSING PLANTS
SUPPLYING EXPORT COMMITMENTS

OIL AND GAS CONSERVATION BOARD
MARCH, 1962

Each year the Alberta Oil and Gas Conservation Board estimates the natural gas reserves of the Province. These estimates are published on a field by field basis in a report called "Reserves of Natural Gas, Natural Gas Liquids and Crude Oil of the Province of Alberta". The most recent Conservation Board estimates, of December 31, 1961, are about to be published. Those of you interested may obtain copies of the report through the Oil and Gas Conservation Board.

Table II presents a brief summary of the preliminary Board reserve estimates as of the end of 1961. The table shows that the total reserves of the Province are some 31.2 trillion cubic feet. Of this reserve, 3.2 trillion cubic feet are presently considered beyond economic reach. The reserves within economic reach are made up of about 22.0 trillion cubic feet of non-associated gas, about 3.5 trillion cubic feet of gas cap gas, and some 2.5 trillion cubic feet of solution gas.

TABLE II. REMAINING MARKETABLE GAS RESERVES
IN THE PROVINCE OF ALBERTA - DECEMBER 31, 1961
(Billions of Cubic Feet)

(1) Type of Reserve	(2) Within Economic Reach	(3) Beyond Economic Reach	(4) Total
Non-Associated	22,024	2,755	24,779
Associated	3,490	142	3,632
Solution	2,497	316	2,813
Total	28,011	3,213	31,224

The location of the major reserves of natural gas (those greater than 100 billion cubic feet) is shown in Figure 3. A color scheme has been used to illustrate the approximate size of the reserves. A study of Figure 3 and of the detail of the reserves included in the previously mentioned Conservation Board report, reveals that there is a fair concentration of gas cap and solution gas in the general Edmonton area. Since this gas is the major source of ethane, propane and butanes, it is not surprising that Edmonton seems the favored location for the industry in Alberta.

Transportation and Marketing of Natural Gas

Following the processing of the natural gas (if this is required) the specification gas is transported to various markets by pipe line. Gas presently being produced in Alberta is being delivered to local markets and to extra-provincial markets. The removal of gas from the Province is regulated by the Oil and Gas Conservation Board under the terms of The Gas Resources Preservation Act, 1956. The present policy of the Board and the Government of Alberta is to permit the removal from the Province only of gas which is surplus to the thirty year future requirements of Alberta. The Board includes in its estimate of the future requirements of the Province a generous allowance for the present and future petrochemical industry.

Markets within the Province include the requirements for domestic, commercial and industrial uses. These requirements are served by two large utility companies centering about the cities of Edmonton and Calgary, and by several smaller utility companies. In some instances large industrial consumers are supplied by direct sale from the producers.

Present extra-provincial movements of Alberta gas include those of Trans-Canada Pipelines Limited (moving gas to Eastern Canada and the United States), Alberta and Southern Company (moving gas to California), Westcoast Transmission Co. Ltd. (moving gas to British Columbia and the Western United States), Many Islands Pipelines Ltd. (moving gas to Saskatchewan), Canadian-Montana Pipeline Company (moving gas south to the United States) and Peace River Transmission Co. (moving gas to the Town of Dawson Creek, B.C.). The routes of the major natural gas pipe lines are shown in Figures 1 and 2. Figure 1 shows those pipe lines which serve markets within the Province, while Figure 2 shows those lines which serve extra-provincial markets.

The producing rate for natural gas reserves depends to a great extent on the particular market being served by the reserve. In situations where the gas is being exported the producing rate is of the order of one million cubic feet per day for each eight billion cubic feet of reserves, and the gas is produced at a high load factor (usually 80 to 90 per cent). In cases where the gas is serving local requirements the producing rate averages about one million cubic feet per day for each nineteen billion cubic feet, and the load factor varies from some 30 to 80 per cent. The overall producing rate for all natural gas reserves in the Province is about one million cubic feet per day for each 13 billion cubic feet of reserves.

Table III is a summary of the present allocation of gas reserves to various markets within the Province exclusive of the Peace River Area. It can be seen that of the present marketable gas reserves of some 29.8 trillion cubic feet, about 12.1 trillion cubic feet are necessary to look after the thirty year requirements of the Province and an additional 16.0 trillion cubic feet are required to meet existing commitments for removal of gas from the Province. This means there is presently a surplus in order of 1.7 trillion cubic feet of natural gas in Alberta. If recognition is given to gas reserves not yet discovered by including those reserves which the Board is confident will be developed over the next two years, the present surplus of gas in the Province becomes some 5.5 trillion cubic feet. Bearing in mind the trends, the table shows the very substantial reservation of gas for the future needs of the people and industries of Alberta and the healthy surplus beyond these requirements and the commitments to export.

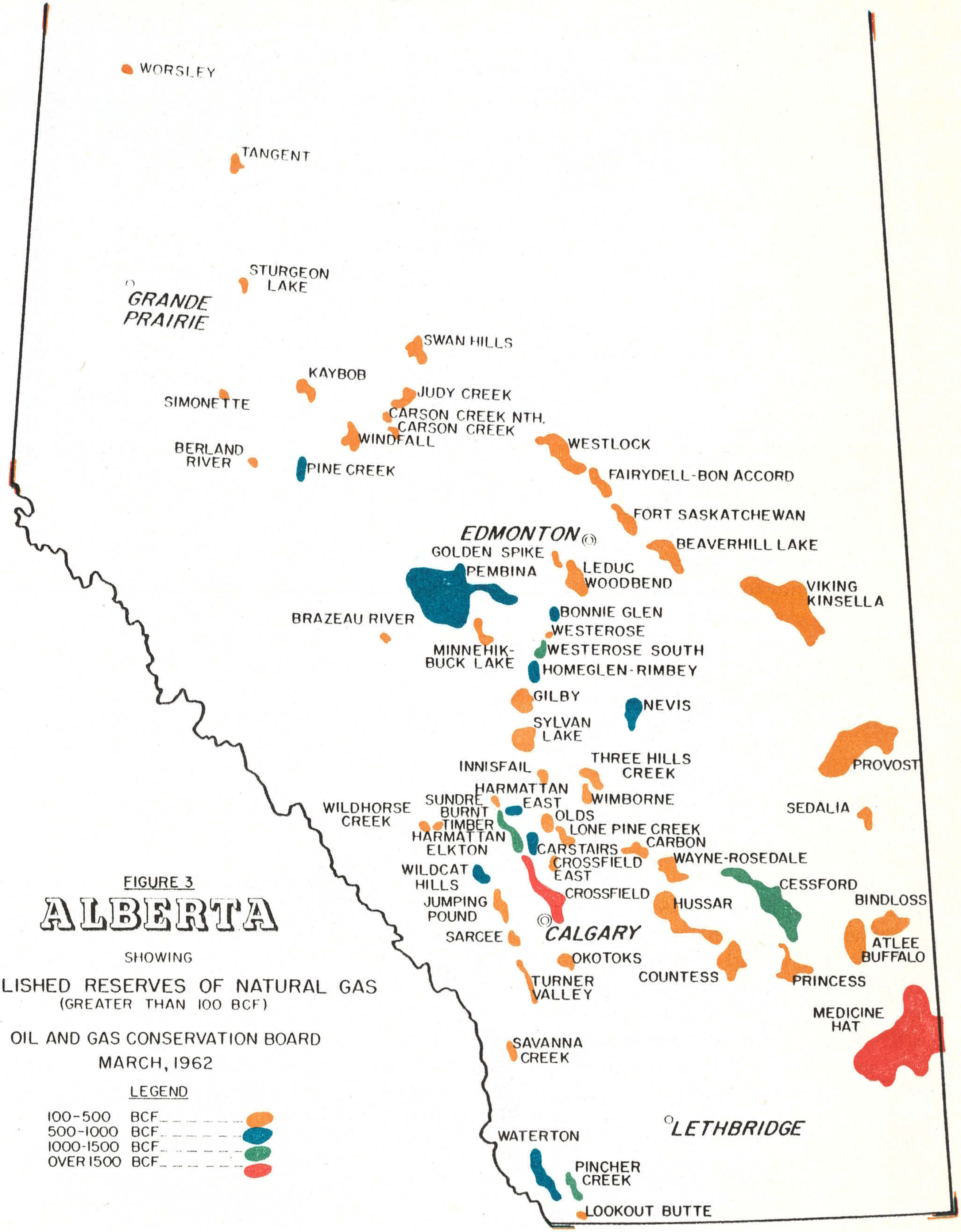

FIGURE 3

ALBERTA

SHOWING

ESTABLISHED RESERVES OF NATURAL GAS
(GREATER THAN 100 BCF)

OIL AND GAS CONSERVATION BOARD
MARCH, 1962

LEGEND

100-500 BCF 🟧
500-1000 BCF 🟦
1000-1500 BCF 🟩
OVER 1500 BCF 🟥

TABLE III. ALLOCATION OF RESERVES NECESSARY TO MEET FUTURE REQUIREMENTS OF ALBERTA AND PRESENT EXPORT COMMITMENTS EXCLUSIVE OF THE PEACE RIVER AREA (1000 Btu BASIS)

LOCAL REQUIREMENTS

Area	Marketable Gas Necessary to Meet 30 Year Requirements Bcf
Canadian Western Natural Gas Company Limited	4,860
Northwestern Utilities Limited	4,750
Medicine Hat	690
Wabamun - Hinton	440
Remainder of Province (North)	800
Remainder of Province (South)	600
Provincial Total	12,140

EXPORT

Exporting Firm	Marketable Gas Needed for Protection to Terminal Date of Permit Bcf
Alberta and Southern Gas Co. Ltd. Permit AS 59-1	4,566
Alberta and Southern Gas Co. Ltd. Permit AS 60-2	480
Canadian Montana Pipelines Limited Permit CM 61-2	248
Many Islands Pipelines Ltd. Permit SPC 57-1	572
Trans-Canada Pipe Lines Limited Permit TC 54-1	5,691
Trans-Canada Pipe Lines Limited Permit TC 59-2	1,901
Trans-Canada Pipe Lines Limited Permit TC 60-3	455
Westcoast Transmission Company Limited Permit WC 59-3	1,489
Group of Producer Permits in Medicine Hat Field	570
Total	15,972

Total Marketable Gas Reserves in Province (Exclusive of Peace River Area)	31,602 Bcf
Marketable Gas Necessary to Meet 30 Year Requirements	12,140 Bcf
Marketable Gas Needed for Protection to Terminal Date of Permits	15,972 Bcf
Surplus	3,490 Bcf
Gas Available from Two Years of Trends	3,800 Bcf
Overall Surplus	7,290 Bcf

One may conclude that high methane gas for fuel or raw material purposes is available in any volume which the petrochemical industry may require. Another important indication from the table is that since the gas destined for export is processed in Alberta before being exported, natural gas liquids are available from all wet gas produced not merely from that which is used locally. Continuity of production of these liquids is assured by the need for uninterrupted delivery of fuel gas to the local and export markets.

Reserves of Natural Gas Liquids

The reserves of natural gas liquids may be estimated from the reserves of natural gas, on the basis of the composition of the gas and the per cent recovery anticipated for each component of the gas. For the pentanes and higher hydrocarbons, recovery is virtually 100 per cent and is necessary in order to meet pipe line dew point specifications. The recovery factor for propane and butanes depends on the composition of the gas and to a great extent on the marketing opportunities for these products.

The Oil and Gas Conservation Board has studied the individual gas reserves in detail and has arrived at an estimate of the minimum or normal recoveries for natural gas liquids that can be anticipated under marketing conditions similar to those that exist today. The Board has also estimated higher recoveries that might be justified if there were an increased economic incentive to recover these products.

Table IV presents the Board's estimate of the recoverable reserves of natural gas liquids in the Province of Alberta as of December 31, 1961. The table gives the marketable gas reserves, the liquid recovery ratios, and the liquid reserves individually for all fields having total natural gas liquid reserves greater than five million barrels. Also included in the table is a supplementary listing which shows the additional propane and butanes that may be recovered as a result of the reprocessing of pipe line gas, and the additional reserves that could be counted upon if increased economic incentive for their recovery should develop.

The reprocessing of pipe line gas can be anticipated mainly as a source of supply of liquids for the petrochemical industry, and is possible because substantial quantities of propane and butanes along with all of the ethane, are left in the gas at processing plants. This reprocessing can normally be expected to take place in conjunction with or nearby petrochemical plants and is economically possible, notwithstanding the low liquid content, because of the large quantities of gas available in a main transmission line. It should be pointed out that portions of the additional reserves shown as recoverable under increased economic incentive could very well be recovered from pipe lines at some central point.

Table IV shows that the total recoverable natural gas liquid reserves under present economic conditions is some 685.5 million barrels. This is made up of about 143 million barrels of propane, 108 million barrels of butanes, and some 435 million barrels of pentanes plus. The reprocessing of pipe line gas will likely add to these

TABLE IV. RECOVERABLE RESERVES OF NATURAL GAS LIQUIDS IN THE PROVINCE OF ALBERTA - DECEMBER 31, 1961

(1) Field, Area or plant	(2) Zone	(3) Established Marketable Reserves of Natural Gas Bcf	(4) Liquid Recovery Ratios Bbls/MMcf (Marketable Gas)			(5) Recoverable Liquids Millions of Barrels			(6) Total
			Propane	Butanes	Pentanes Plus	Propane	Butanes	Pentanes Plus	
Bonnie Glen (1)	Leduc	622	34.0	22.0	24.0	21.1	13.7	14.9	49.7
Carson Creek	Beaverhill Lake	160	10.4	11.6	74.0	1.7	1.9	11.8	15.4
Carson Creek North	Beaverhill Lake	169	12.0	10.0	8.0	2.0	1.7	1.4	5.1
Carstairs	Mississippian	768			25.0			19.2	19.2
Crossfield	Mississippian & Wabamun	2050			20.0			41.0	41.0
Gilby	Blairmore, Jurassic & Mississippian	453			13.8			6.3	6.3
Harmattan-East	Mississippian	621			31.0			19.3	19.3
Harmattan-Elkton	Mississippian	1068			27.0			28.8	28.8
Homeglen-Rimbey	Leduc	768	5.0	7.0	32.0	3.8	5.4	24.6	33.8
Kaybob	Notikewin, Cadomin & Beaverhill Lake	321	7.5	8.0	9.0	2.4	2.6	2.9	7.9
Leduc-Woodbend	Leduc & Nisku	381	24.0	18.0	9.0	9.1	6.9	3.4	19.4
Lookout Butte	Mississippian	200	8.0	11.0	83.0	1.6	2.2	16.6	20.4
Nevis (2)	Leduc & Nisku	556	7.0	7.0	15.0	3.9	3.9	8.3	16.1
Pembina	Cardium & Blairmore	650	16.9	12.4	14.2	11.0	8.1	9.2	28.3
Pincher Creek	Mississippian	1068	5.0	6.0	20.0	5.3	6.4	21.4	33.1
Redwater	Leduc	46	105.0	96.0	35.0	4.8	4.4	1.6	10.8
Simonette (3)	Wabamun & Leduc	173	5.7	9.4	56.0	1.0	1.6	9.7	12.3
Swan Hills (4)	Beaverhill Lake	661	87.0	45.0	23.0	57.5	29.7	15.2	102.4
Sylvan Lake	Blairmore & Mississippian	190	12.0	9.0	11.0	2.3	1.7	2.1	6.1
Turner Valley	Rundle	266	6.1		18.9	1.6		5.0	6.6
Waterton	Mississippian	899			35.0			31.5	31.5
Westerose South	Leduc	1540	7.0	9.4	24.0	10.8	14.5	37.0	62.3
Wildcat Hills	Mississippian	600			11.5			6.9	6.9
Wimborne	Leduc	195	4.7	10.4	44.4	0.9	2.0	8.7	11.6
Windfall	Leduc	400			120.0			48.0	48.0
Worsley	Leduc	220			28.0			6.2	6.2
Sub-Total						140.8	106.7	401.0	648.5
Other Reserves (5)						2.1	1.1	33.8	37.0
Total						142.9	107.8	434.8	685.5

Table IV (Continued)

ADDITIONAL RESERVES EXPECTED FROM THE REPROCESSING OF PIPELINE GAS

					15.0	8.0	-	23.0
					157.9	115.8	434.8	708.5

ADDITIONAL RECOVERABLE RESERVES THAT MAY RESULT FROM INCREASED ECONOMIC INCENTIVE TO RECOVER PROPANE AND BUTANES

Increased Production (6)					21.0	8.0		29.0
Carstairs	Mississippian	768	6.0	5.9	4.6	4.5		9.1
Crossfield	Mississippian & Wabamun	2050	4.0	4.5	8.2	9.2		17.4
Gilby	Blairmore, Jurassic & Mississippian	453	2.5	2.6	1.1	1.2		2.3
Minnehik-Buck Lake	Mississippian	300	4.9	6.9	1.5	2.1		3.6
Waterton	Mississippian	899	4.8	4.6	4.3	4.1		8.4
Windfall	Leduc	400	12.2	20.2	4.9	8.0		12.9
Sub-Total					45.6	37.1		82.7
Total					203.5	152.9	434.8	791.2

(1) Includes Bonnie Glen, Glen Park and Wizard Lake
(2) Includes Nevis, Fenn-Big Valley and Stettler
(3) Presently considered beyond economic reach
(4) Includes Judy Creek, Swan Hills and Virginia Hills
(5) Includes all fields and other areas where recoverable liquid reserves are estimated at less than five million barrels
(6) Presently considered beyond economic reach

reserves an additional 15 million barrels of propane and 8 million barrels of butanes. Under conditions of increased economic incentive to recover liquified petroleum gases, the liquid reserves might total as much as 790 million barrels. This reserve would be made up of over 200 million barrels of propane, some 150 million barrels of butanes, and 435 million barrels of pentanes plus.

The location of the natural gas liquid reserves is shown in Figure 4. A study of the figure along with Table IV reveals that there is quite a concentration of recoverable reserves of propane and butanes in the Edmonton area. A substantial per cent of the propane and butanes that might be recovered due to increased economic incentive is distributed quite widely throughout the Province. In addition to this, quantities of these liquids could be recovered from many points along major gas transmission lines.

Reserves of Ethane

Since the recovery of ethane is not widely carried out in Alberta and yet is potentially of utmost importance to the petrochemical industry, the ethane reserves present a special situation. Ethane is recovered from gas only if a market for the ethane exists, since its removal is not necessary in order to meet pipeline dew point specifications. It then follows that ethane is more likely to be recovered through the reprocessing of pipe line gas than at a processing plant in the field.

The recovery of ethane from all gases is certainly not economic because many gases contain insufficient ethane to warrant the expensive processing. A list of the gas reserves that contain the major potentially recoverable reserves of ethane is presented in Table V. The table shows the field or area and pool, along with the marketable gas reserves and the approximate per cent ethane in the marketable gas. It can be seen that many fairly substantial gas reserves in the Province contain as much as twenty percent ethane. The ethane content of the pipe line gas at various locations in the Province is given in Figure 5. Table V and Figure 5 indicate that volumes of ethane adequate for any petrochemical purpose could be obtained at many different locations in the Province.

Refinery Gas Liquids

I come now to a brief reference to refinery gases as a source of light hydrocarbons for the petrochemical industry. Crude oil, even after the removal of most of the solution gas, still contains a small amount of dissolved gas which is released during refining operations. This dissolved gas is augmented by decomposition products of thermal and catalytic cracking. The amount and composition of these refinery gases depends upon the nature of the oil and the extent to which it has been exposed to the atmosphere and allowed to weather, and upon the details of the refinery processing.

Refinery gases are an important source of petrochemical raw materials in regions such as Sarnia where large scale refining operations are carried out and where natural gas liquids are not available. While Alberta's petrochemical industry may be

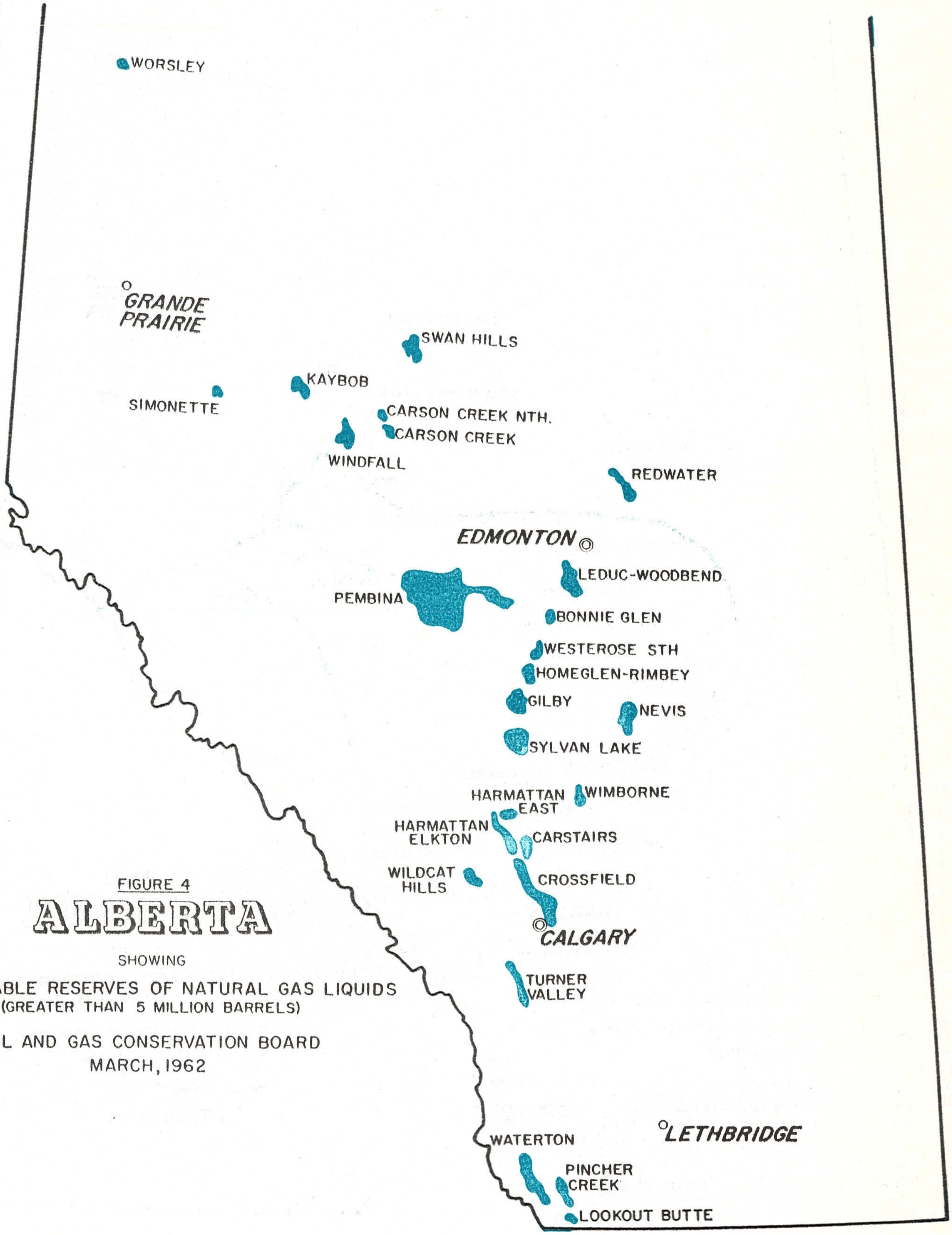

FIGURE 4

ALBERTA

SHOWING

RECOVERABLE RESERVES OF NATURAL GAS LIQUIDS
(GREATER THAN 5 MILLION BARRELS)

OIL AND GAS CONSERVATION BOARD
MARCH, 1962

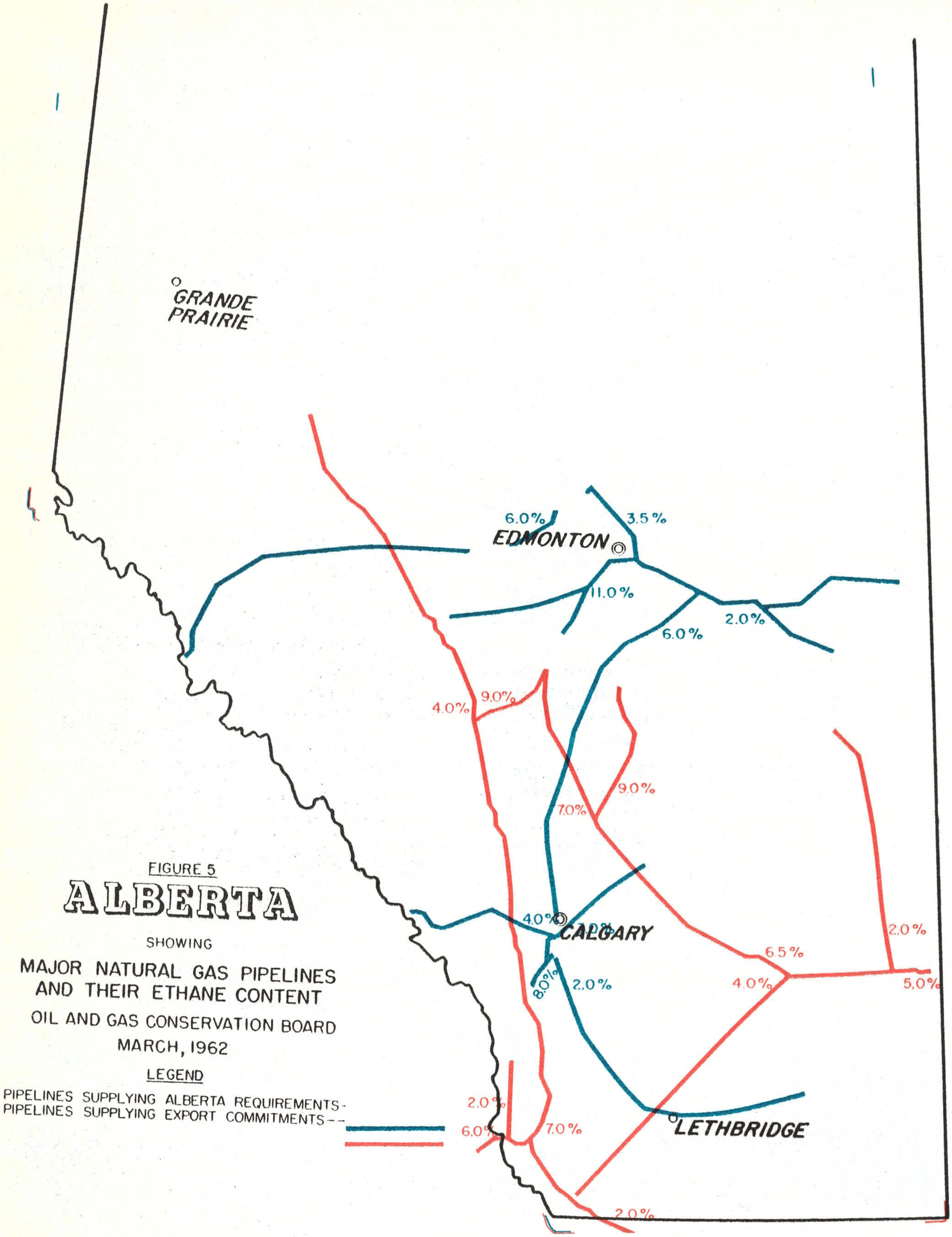

FIGURE 5

ALBERTA

SHOWING

MAJOR NATURAL GAS PIPELINES AND THEIR ETHANE CONTENT

OIL AND GAS CONSERVATION BOARD

MARCH, 1962

LEGEND

PIPELINES SUPPLYING ALBERTA REQUIREMENTS-
PIPELINES SUPPLYING EXPORT COMMITMENTS--

TABLE V. GAS RESERVES CONTAINING THE MAJOR POTENTIALLY RECOVERABLE RESERVES OF ETHANE IN THE PROVINCE OF ALBERTA

Field	Pool	Marketable Gas Reserve Bcf	Volume% Ethane
Acheson	Leduc (Solution)	25	19.0
Bonnie Glen	Leduc (Solution)	196	19.0
Carson Creek	Beaverhill Lake (Non-associated)	160	15.5
Carson Creek North	Beaverhill Lake (Solution)	149	16.5
Glen Park	Leduc (Solution)	7	16.5
Golden Spike	Leduc (Solution)	61	13.0
Harmattan-East	Rundle (Associated & Solution)	621	11.0
Harmattan-Elkton	Rundle (Associated & Solution)	1018	10.5
Judy Creek	Beaverhill Lake (Solution)	198	19.5
Kaybob	Beaverhill Lake (Solution)	71	17.0
Leduc-Woodbend	Nisku (Associated)	28	7.0
	Nisku (Solution)	29	15.5
	Leduc (Associated)	300	11.5
	Leduc (Solution)	25	22.0
Redwater	Leduc (Solution)	46	19.5
Swan Hills	Beaverhill Lake (Solution)	404	20.0
Virginia Hills	Beaverhill Lake (Solution)	59	19.0
Westerose	Leduc (Solution)	60	12.0
Westerose South	Leduc (Non-associated)	1275	11.0
Wizard Lake	Leduc (Solution)	89	18.0

expected to depend largely on fuel and light hydrocarbons from natural gas, refinery gases are now supplementing natural gas liquids and will continue to do so in the future.

Refinery gases are of much different composition than natural gases. They contain hydrogen, methane, ethane, ethylene, propane, propylene, butanes and butylenes. They are much lower in methane and much higher in the higher hydrocarbons and they contain unsaturated gases not found in natural gases. Because of the higher proportion of the higher hydrocarbons refinery gases are not piped long distances and as a result are only available at or near refineries. In fact, the processing of these refinery gases for the recovery of propane and butanes is usually integrated with the rest of the refinery operations.

A few years ago I made a survey of refiners in Western Canada and obtained information on the yield, composition and disposition of their refinery gases. The survey indicated that both the yield and the composition of the gases varied in a most complex way with the nature of the crude oil and the pressure, temperature, time and catalyst conditions of the refinery processing. Typical yields and compositions appear in Table VI.

TABLE VI. ANALYSES OF
TYPICAL REFINERY GASES

(1) Refiner	(2) A	(3) B	(4) C	(5) D
Type of Refining	Catalytic Cracking	Thermal Cracking	Thermal and Catalytic Cracking	Thermal and Catalytic Cracking
Yield, CF/Bbl	238	234	172	198
Composition:				
Hydrogen and Methane	20.4	26.5	17.0	16.2
Ethane	7.9	19.0	8.5	12.4
Ethylene	8.0	5.0	2.9	2.2
Propane	11.7	20.1	21.6	28.8
Propylene	17.5	10.4	12.7	10.1
Butanes	15.0	12.5	25.0	23.0
Butylenes	19.5	6.5	12.3	7.3
Total	100.0	100.0	100.0	100.0

For the reasons I have mentioned it is very difficult to estimate the reserves of hydrocarbons available from refinery gases for the petrochemical industry. One way to make a reserve estimate would be to estimate the recoverable reserves of crude oil in the Province, and to multiply this estimate by the average yield and composition of refinery gas per barrel of crude oil. Because a substantial proportion of Alberta's crude oil production is transported to and refined in areas other than Alberta, this method is not too helpful in considering Alberta's petrochemical potentialities.

Another approach, is to base the reserve estimate on Alberta's refining capacity, assuming that oil reserves will be available to operate the refineries for a long time into the future. Although Alberta's refining capacity undoubtedly will grow in the future, and refining technology is changing, it seems not unreasonable to take the present refining capacity and the present yields and to estimate the hydrocarbon production for say, a 25-year period. This is what I have done in Table VII. Alberta has been divided into three main areas and the present refining capacity is shown for each area. (The refineries are operating at something like 80 per cent of this capacity). The total gas yield as shown has been estimated and it must be remembered that it is a very rough estimate based on average yield figures of a few years ago. From these estimates and the assumption that 10 per cent of the total gas is recoverable ethane (representing a recovery of from 50 to 75 per cent), 25 per cent of the total gas is propane (reflecting a 75 to 90 per cent recovery), and 35 per cent of the total gas is recoverable butanes (equivalent to an 80 to 90 per cent recovery); the recoverable reserves of refinery gas liquids are calculated. It may be noted that the reserves of hydrocarbons recoverable from the refinery gases total some 65 million barrels and are much less than the reserves of the corresponding hydrocarbons from natural gas.

Marketing of Natural Gas Liquids

The rate at which the natural gas liquids are produced depends upon the rate of production of the gas reserves and the applicable liquid recovery ratio. The liquid recovery ratio varies over a wide range depending upon the composition of the actual gas and the marketing opportunities. In the case of propane current recoveries vary from as low as 3.0 to about 100 barrels per million cubic feet while butane and pentanes plus recoveries vary from about 4.0 to 90 and 1.0 to 120 barrels per million cubic feet of gas. The provincial averages are of the order of 4.5, 4.0 and 22.0 barrels per million cubic feet of propane, butanes and pentanes plus, respectively.

The total production of natural gas liquids is now of the order of 35,000 barrels per day. With the completion of processing plants now under construction or contemplated it is expected to grow rapidly - probably to a level of 90,000 - 100,000 barrels per day by 1965. The corresponding figures for propane are some 7,000 barrels per day growing to 13,000 - 18,000 barrels per day. For butanes the present production is approximately 5,500 barrels per day and growth to 10,000 - 16,000 barrels per day is anticipated. The pentanes plus figures are 22,000 barrels per day currently, growing to about 70,000 barrels per day in 1965.

As in the case of fuel gas the removal of propane and butanes from the Province is regulated by the Oil and Gas Conservation Board under the terms of the Gas Resources Preservation Act. The general policy is to restrict long term export to propane and butanes surplus to present and future requirements of Alberta. Short term export is permitted for short term surpluses. There are no Alberta restrictions on the export of pentanes plus.

TABLE VII. RESERVES OF LIGHT HYDROCARBONS FROM CRUDE OIL REFINING IN THE PROVINCE OF ALBERTA

(1) Area	(2) Refining Capacity BPD	(3) Total Gas Yield CF/Bbl	(4) 25 Year Total Gas Bcf	(5) Ethane[1] Ethylene Bcf	(6) Propane[2] Propylene Bbls (Millions)	(7) Butanes[3] Butylenes Bbls (Millions)
Calgary	23,700	200±	43	4.3	6.9	11.6
Edmonton	48,200	200±	88	8.8	14.0	23.7
Other Areas	26,600	100±	24	2.4	3.9	6.4
Total	98,500		155	15.5	24.8	41.7

(1) Taken at 10% of total gas (50-75% recovery)
(2) Taken at 25% of total gas (75-90% recovery)
(3) Taken at 35% of total gas (80-90% recovery)

During the past year the Oil and Gas Conservation Board was called upon to make detailed studies and forecasts of the production and Alberta requirements of propane and butanes. These studies were presented in a public Report to the Lieutenant Governor in Council in June 1961, and have been recently brought up to date. In the studies generous allowance was made for the present and anticipated future requirements of propane and butanes for all purposes including those of the petrochemical industry.

In the case of propane the studies indicate an approximate year-round balance between supply and demand at the present time but a rapidly developing surplus levelling off in 1965 or so. The extent of this surplus depends upon the plant recoveries. It will not be lower than about 4,000 barrels per day; it could be as high as 12,000 barrels per day.

In the case of butanes there is a present surplus of some 2,000 barrels per day. This is expected to grow to a minimum of 7,000 barrels per day by 1965 or so. If markets develop and there is an incentive for the producers to increase recoveries the surplus could reach 15,000 barrels.

Like butanes, pentanes plus is already surplus to Alberta's own requirements. The current surplus of nearly 20,000 barrels per day is expected to double within the next three or four years and to level off at 40,000 - 50,000 barrels per day.

Conclusion

In concluding this review may I say that nature's endowment to Alberta, the exploratory efforts of Alberta's oil and gas industry, and the policy of the Government and the Oil and Gas Conservation Board combine, I think, to give a uniquely favorable situation and an assured source of supply of fuel gas and raw materials for the petrochemical industry. I have not dealt with price. Yet, even given all else, price is a major factor. The producers and owners of these hydrocarbons want the best price they can get. The petrochemical industry needs them at the lowest price possible to help overcome transportation charges on the products it makes. This remains for negotiation between supplier and purchaser. I do not see a distress price situation developing but with the growing surpluses there should be opportunities for long term contracts fair to the producers and distributors and attractive to new petrochemical industries.

Acknowledgment

The very great assistance of G. J. DeSorcy, Assistant Chief Gas Engineer, Oil and Gas Conservation Board, in the preparation of the material for the tables and figures is acknowledged.

Mr. R. J. Abercrombie, Canadian Petroleum Association, Calgary, Alberta: Would you, Dr. Govier, please comment on the present average selling price of propane and to what level these prices would have to fall before you would consider them at a distress level. You stated these would not fall to a distress level, so what price or distress level did you have in mind?

Dr. G. W. Govier, Dean of Engineering, University of Alberta and Deputy Chairman of Alberta Oil and Gas Conservation Board: I did not think the development of the surpluses that I referred to would result in these hydrocarbons being made available at prices below or even equal to their fuel value. In other words, their BTU equivalent value as compared with gas prices, but I am not prepared to express this in terms of cents per gallon or the equivalent.

Mr. E. H. Parsons, Calgary Power Ltd., Calgary, Alberta: Would you, Dr. Govier, outline your thoughts on the future of pentanes plus fractions as feed stocks for the petrochemical industry?

Dr. G. W. Govier: At the present time, of course, pentanes plus or what most of us refer to as the natural gasoline and condensate fraction, are being used almost exclusively as the equivalent of a light grade of crude oil and these materials are going to crude oil refining plants. I, personally, believe that in the future more and more of these materials will go to petrochemical processing plants as raw materials. I think the proportion or the total volumes of pentanes plus that are used for such purposes will probably, for a long, long while, be less than the volumes of propane and butane so used. But I do believe that we would not completely discount the possibility of the petrochemical use of the pentanes plus fraction.

HISTORY OF THE PETROCHEMICAL INDUSTRY IN ALBERTA

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Mr. Istvanffy was born in Irricana, Alberta. He received his secondary education in Irricana and Calgary, and attended the University of Alberta, receiving the degrees of B.A. in 1948 and M.A. in 1950. He started with the Alberta Government in 1950 and is at present the Director of the Alberta Bureau of Statistics. He is a member of the Institute of Public Administration of Canada.

The topic "History of the Petrochemical Industry of Alberta" has been assigned to me. The topic serves to present an opening to illustrate how very up-to-date and forward-looking we Albertans are. The term "petrochemical" came into our language comparatively recently -- I am told it was first used in 1942. Our first real petrochemical plant came into operation in 1941 as part of our war effort. So in typical Alberta fashion we were actively in the petrochemical business before we knew it.

So recently coined is the term "petrochemical", that it must be defined for the purpose of this paper. We will treat as being petrochemical plants, all those which use the light hydrocarbons as the basic raw materials for further manufacture. In addition, we will include plants which utilize natural gas constituents as basic materials in the processing or refining of other raw materials. When listing our petrochemical firms, we will also include those plants which further process or manufacture basic petrochemicals into consumer items or materials. Not included as petrochemicals, for some inexplicable reason fully appreciated by chemists and engineers, no doubt, are the oil refineries and sulphur recovery plants of the province. The actual term "petrochemical" appears to infer those chemicals or substances derived from, or separated out from, natural gases or petroleum, and formed or combined into a variety of other chemicals or substances ready for use in other industries. As you can see that is a layman's interpretation.

Before mentioning our roster of petrochemical plants, it will be useful to go back in time and set the stage. Natural gas was discovered near Medicine Hat before the turn of the century. It provided the initial impetus to the first wave of industrialization in that city. Around 1910 a pipeline was built to carry gas from Bow Island to Lethbridge and Calgary and points between. A few years later, gas was found in Turner Valley. It was in such quantities that during the 1920's and 1930's we southern Albertans enjoyed a perpetual sunset watching such a useless and unwanted commodity as natural gas being flared. Even then, we worried about this wastage of an important natural resource. However, the control of Alberta's natural resources was vested at that time in the Ottawa Government, and our problems and worries, as usual, were not of major national concern.

During the early 1920's, the Viking-Kinsella sweet gas field was discovered and began supplying the City of Edmonton.

Late in 1930, control of their own mineral resources was turned over to the governments of the prairie provinces and we became to some extent, masters of our own destinies. However, another (shall I call it natural?) phenomenon was in progress; the Great Depression, which both sapped and absorbed all our energies. It was not until 1938 that the Oil and Gas Conservation Act was passed implementing regulations and controls to prevent excessive flaring of gas and to rationalize crude oil production. The experience gained in the administration of this Act in the next few years stood us in good stead when our great expansion began after the discovery of the Leduc oil field in 1947. Suffice it to say that a major objective of the controls is to eliminate wastage of any economically usable gas fractions or of crude oil.

Following the discovery of the Leduc field numerous major oil companies moved into Alberta and began a vigorous campaign of discovery and "proving up" of other oil fields throughout other areas of the province. Primarily, they were searching for crude oil. Almost unavoidably, however, they discovered tremendous volumes of natural gas as well. In the early years many of these gas finds were regarded almost as nuisances as well as assets. Small local markets, scattered gas finds -- it was uneconomical to do any thing with the wells except to cap them, and hope that the gas fields supplying Calgary and Edmonton would someday give out. (Personally, I remember that the statisticians in Ottawa were most upset in the early 1950's because Western oil firms were admitting to huge sums invested each year in oil exploration, but were not indicating contemplated expenditures on gas exploration. They wouldn't believe that we were finding so much gas without deliberately looking for it).

Let us stop for a moment and look at the situation as it was about 1950. Our estimated disposable reserves of natural gas were just under ten trillion cubic feet as compared with about four trillion at the end of the war. We were just nicely getting used to the idea that the mining of crude oil could be beneficial to all Albertans. The idea was stirring that new industries might be attracted through the presence of oil and gas. An overriding consideration was that we might too easily export all our oil and gas and with them let go our chances for developing industries here. There seemed the concurrent possibility that not only might the price go higher, but that we might export so much gas that none would be left for local use and convenience thirty or sixty years hence.

Accordingly, the Honourable the Premier clearly laid down the principle that there would be no exports of gas from the province until reserves adequate for present and foreseeable needs had been proven. In effect, this meant that gas supplies adequate for domestic use and industrial use for thirty years from a given date must be held in reserve. A generous allowance is regularly made for probable future industrial use.

Remember we are still in 1950. With only ten trillion cubic feet of gas in reserve, with future discoveries yet very much an unknown quantity, it was not known that gas ever would be exported from the province. The Premier's firm statement that provision would be made for its needs was reassuring to industry new here, or contemplating coming into the province. Added to this, in any case, was the distinction drawn between the methane, useful mainly for heating purposes, which might under certain circumstances be exported -- and the other gas fractions or liquid petroleum gases which had potential value as industrial raw materials. These latter were to be extracted from the raw gas and retained in the province -- or exported under special permits. As Dr. Govier has indicated, engineering considerations dictated their removal in any case. In the early 1950's they were not produced in quantities sufficient to justify a separate pipeline to other markets, and specially constructed pipelines were deemed necessary in those days.

It was under those current appraisals of the situation that some major petrochemical firms built plants in the Edmonton area in the early 1950's.

Since 1950 our natural gas reserves have increased by over two trillion cubic feet a year on the average. They now exceed 31 trillion cubic feet as compared with ten trillion in 1950. It became increasingly apparent that we had adequate gas for export. Permits were issued to allocate certain fields and stated quantities to export markets. Accordingly the Trans Canada Pipeline was completed in 1957 to eastern Canada; the Westcoast Transmission Pipeline to B.C. and the north western United States was completed in 1957. In 1961 the Alberta & Southern Pipeline was completed which serves the general California area of the U.S.A. In effect, export is restricted mostly to dry gas, or methane. We still retain full control of the other gas fractions suitable for industrial use.

In fact we do more than that. As Dr. Govier has indicated, it is necessary to remove most of the lighter gas fractions from the natural gas before export -- hence the string of gas processing plants running the length of Alberta from the American border to the Peace River district.

As of the end of 1961 we were producing propane at the rate of 2.5 million barrels a year; butane at a rate of 2.0 million barrels a year; and condensates at a rate of over 5 million barrels a year. And all this before the pipeline began carrying natural gas to California in volume. Over the next few years these production figures should more or less triple as the gas markets build up.

These data I believe provide the basic information for understanding why we have a petrochemical industry now -- and the basis for our hopes of having an even more impressive one in the decades ahead. We have the raw materials.

However, raw materials alone are not the basis for any industry. Even more important are markets and costs of getting the products to markets. Alberta is not blessed with a deeply indented coastline, and splendid harbours giving us easy access to world markets. Nor are we within easy driving distance of the great centres of even North American population. Our freight rates seem designed to exclude products of other areas -- and at the same time to make it difficult for our produce to reach continental and world markets. The freight tariffs on our manufactured products very often make it easier to ship out the raw materials for processing elsewhere -- particularly to areas near population concentrations. It is fervently to be hoped that as a result of the recent inquiry into the freight structure of Canadian railways, that a structure more impartial as between regions may be evolved.

Let us now examine the dates when the individual petrochemical firms entered our area and relate each to the conditions and prospects of its time.

1. Our first plant, Alberta Nitrogen Products Ltd., was built in the early days of World War II in order to produce essential war materials -- ammonia and ammonium nitrate. It was built at Calgary to utilize the natural gas from Turner Valley. It was born of necessity, and had to be built at the site of the raw materials. After the war, the plant was sold to Consolidated Mining and Smelting Company to manufacture fertilizers. In 1960 - 61 it was expanded to produce urea as well. It produces mainly for export.

2. Early in the 1950's a group of unrelated plants were built. All came essentially because of the availability of raw materials for processing or for treating other raw materials. This group included Canadian Chemical Company which produces an impressive and varied list of chemicals, and which utilizes some of these chemicals in the manufacture of cellulose acetate or celanese using wood pulp from its B.C. plant and thence into yarn.

The Canadian Industries Ltd., plant produces polythene flakes from ethane from natural gas. The bulk of these polythene flakes are exports.

Sherritt Gordon Mines Ltd., plant at Fort Saskatchewan utilizes natural gas to produce ammonia for the treatment of its ores to produce refined nickel and cobalt. Ammonium sulphate fertilizers and urea are also manufactured.

The Canadian Industries Ltd., plant at Calgary utilizes nitric acid derived from ammonia in the production of explosives.

3. In the middle 1950's another group of plants, principally in the Edmonton district, were built. Monsanto Canada Ltd., and Canadian Marietta Ltd., utilize some locally produced petrochemicals in making the glues and adhesives used by the local plywood plants. Other plants, Polychemical Ltd., and Polytubes Ltd., use C.I.L. polythene flakes in making tubes and pipes and other consumer items.

4. In 1956, Northwest Nitro Chemicals Ltd., built a large fertilizer plant close to its gas fields near Medicine Hat. It concentrates on the ammonium phosphate fertilizers.

5. Then in the early 1960's two other major companies made their debut on the Alberta scene, Edmonton area. These were Dow Chemicals Ltd., with a plant at Fort Saskatchewan for the manufacturing of glycols and amines, essentially for the western Canada market.

The Naugatuck Chemicals Ltd., plant east of Edmonton produces wood preservatives and agricultural chemicals also mainly for western Canada markets. Other plants such as Western Chemicals Ltd., producing caustic soda, chlorine and now calcium chloride, are here and only possible because of the presence of the other petrochemical plants.

These various plants break into two groups: those which produce primarily for export and those which will serve local or western Canada markets. Canadian Chemical Company; Canadian Industries Ltd.; Sherritt Gordon; Consolidated Mining and Smelting and North West Nitro produce for export. The C.I.L. explosives plant, Monsanto Canada Ltd., and Canadian Marietta, Polychemical Company and Polytubes produce for the local market. The latest firms, Naugatuck and Dow, both are designed to serve local markets.

For the purpose of assessing the range of chemical possibilities brought by the development of our oil and gas resources, we must at least mention the string of gas processing plants running from the Peace River country to the American border. These plants are designed to extract from natural gas all excess fractions but the heat producing methane. Another most useful by-product is the sulphur now being produced at a rate of about a million tons per year.

In the early 1960's the question of exporting liquefied petroleum gases from the province became a vital issue. The present and forecast exports of natural gas indicated that there would be substantial volumes of L.P.G.'s produced over and above immediate local requirements. Dr. Govier has given you the detailed figures. One company proposed to construct a gas gathering system and a pipeline in which to transport the L.P.G.'s to the general Chicago area of the U.S.A. Export was to be based on the premise that local markets were presently inadequate. There seemed to be a further premise that there was little or no likelihood that major processors would enter either Alberta, or western Canada, or central Canada to utilize the gases on Canadian soil -- and thereby benefit the nation through the additional investment involved, the additional employment opportunities the investments would provide; and the increments in value to Canada through exports of manufactured or semi-manufactured products rather than of raw materials. Suffice it to say that the pipeline application was turned down by the Alberta Oil and Gas Conservation Board.

PETROCHEMICAL PLANTS - ALBERTA

Name of Firm	Announced Year	Initial Operation Year	Expansion-Years	Announced Cost of Plant & Equipment	Average Employment	1961 Estimated Percentage Of Product Exported to Foreign Countries	List of Products
				$	No.	%	
The Consolidated Mining and Smelting Company of Canada Ltd., CALGARY - Alberta. (Formerly - Alberta Nitrogen Products Ltd.,)	1940	1941		6,000,000	285	85 %	Anhydrous Ammonia; Ammonium Nitrate; Urea; Nitrate Urea Solutions.
			1942	2,000,000			
			1948	1,000,000			
			1953-54	500,000			
			1960-61	5,000,000			
Canadian Chemical Company Ltd., EDMONTON - Alberta.	1951	1953		78,000,000	775	70 %	Acetate & Arnel Yarn; Acetate Staple Fibre; Cigarette Tow; Cellulose; Acetate Flake; Xanthates; Acetic Anhydride; Acetic Acid; Acetone; n-Butanol; Methanol; n-Propanol; Formaldehyde; Glycol propylene; Glycol dipropylene; Methyl isobutyl carbinol; Methyl isobutyl ketone; Pentaerythritol; Acetaldehyde; n-Butyl acetate; Blended Solvents; Isobutanol, Methyl amyl acetate, n-Butyl acetate, CF 81 - Frothing Agent, n-Propyl acetate.
			1955	500,000			
			1957	2,000,000			
			1960	5,000,000			
			1961	400,000			
Canadian Industries Ltd., EDMONTON - Alberta.	1951	1953		16,000,000	305	50 %	Polyethylene.
			1954	250,000			
			1959	9,000,000			
Sherritt Gordon Mines Limited, FORT SASKATCHEWAN - Alberta.	1951	1954		24,000,000	550	93	Nickel, Cobalt, Copper Sulphide, Anhydrous Ammonia, Ammonium Sulphate, Urea - (3rd quarter 1962), Nickel Coin Blanks, Cobalt and Nickel strip, wire and rod.
			1955	500,000			
			1955	850,000			
			1955-58(incl.)	5,500,000			
			1958-59	1,600,000			
			1960-61	520,000			
			1961-62	3,000,000			
Northwest Nitro-Chemicals Ltd. MEDICINE HAT - Alberta.	1955	1956		23,000,000	285	70-75	Sulphuric Acid, Nitric Acid, Phosphoric Acid; Ammonium Phosphate, Ammonium Nitrate, Anhydrous Ammonia.
Dow Chemical Canada Ltd., FORT SASKATCHEWAN - Alberta.	1960	1961		4,000,000	50	-	Glycol and Amines, Pentachlorophenol, Muriatic Acid.
Naugatuck Chemicals, Division of Dominion Rubber Company Ltd. EDMONTON - Alberta.	1960	1961		1,500,000	20	-	Pentachlorophenol, Muriatic Acid, Agricultural Chemicals.

SULPHUR PLANTS - ALBERTA - 1962

Operator	Location	Initial Operation Year	Expansion-Years	Announced Cost of Plant and Equipment	Sulphur Productive Capacity long tons/day
				$	
Shell Oil Company of Canada Ltd.,	Jumping Pound	1952		400,000	35
			1954	500,000	100
Royalite Oil Company Ltd.,	Turner Valley	1952		2,500,000	30
Imperial Oil Limited,	Redwater	1956		2,200,000	9
British American Oil Company Ltd.,	Pincher Creek	1957		25,000,000	225
			1958	4,000,000	675
Texas Gulf Sulphur Company Ltd.,	Okotoks	1959		9,000,000	370
British American Oil Company Ltd.	Nevis	1956		3,000,000	76
			1959	1,500,000	
California Standard Oil Company Ltd.,	Nevis	1959		3,000,000	120
Canadian Oil Companies Ltd.,	Innisfail	1960		4,000,000	100
British American Oil Company Ltd.,	Rimbey	1961		12,500,000	250
Western Leaseholds Ltd.,	Wildcat Hills	1961		6,000,000	105
Pan-American Petroleums Ltd.,	Windfall	1962		20,000,000	650
Home Oil Company Ltd.,	Carstairs	1962		7,500,000	60
Jefferson Lake Petrochemicals Canada Ltd.,	Goleman	1962		10,000,000	375
Petrogas Processing Ltd.,	East Calgary	1962		13,000,000	860
Shell Oil Company of Canada Ltd.,	Waterton	1962		25,000,000	1,400

SECONDARY PETROCHEMICAL AND CHEMICAL PLANTS

(Primarily Supplying Western Canadian Markets)

Name of Firm	Announced Year	Initial Operation Year	Expansion-Years	Announced Cost of Plant & Equipment	Average Employment	List of Products
				$	No.	
Alberta Polytubes Ltd. EDMONTON - Alberta.	1951	1952		27,000	15	Plastic Pipe.
Canadian Industries Ltd., CALGARY - Alberta.	1951	1952		6,000,000	100	Commercial Explosives, Nitric Acid.
Western Chemicals Ltd., DUVERNAY - Alberta.	1951	1953			105	Caustic Soda, Chlorine, Muriatic Acid.
			1955)			
			1956)			
			1959)	10,000,000		
			1961)			
Modern Packaging Company Ltd., CALGARY - Alberta.	1954	1955		40,000	20	Plastic bags.
		1956		125,000		
		1959		60,000		
Inland Chemicals Company Ltd., FORT SASKATCHEWAN - Alberta.	1954	1955		1,000,000	15	Sulphuric Acid, Alum.
		1962		150,000		
Polychemical Industries Ltd., EDMONTON - Alberta.	1955	1956		225,000	30	Plastic Pipe, Couplings, Cups, and Containers.
			1957	200,000		
			1959	80,000		
Northwest Polyrama Ltd., EDMONTON - Alberta.	1955	1956		50,000	16	Plastic Film, Bags and fabricated plastic products.
Canadian Marietta Ltd., EDMONTON - Alberta.	1955	1956		350,000	7	Phenolic and urea formaldehyde resins.
Monsanto Canada Ltd., EDMONTON - Alberta.	1955	1956		500,000	6	Phenolic and urea formaldehyde resins.
Dymer Plastics Ltd., EDMONTON - Alberta.	1959	1960		500,000	11	Rigid plastic foam insulation.
		1961		50,000		
Marpak Industries Ltd., EDMONTON - Alberta.	1961	1962		24,000	5	Plastic bottles.
Isothane Industries Ltd., EDMONTON - Alberta.	1961	1962		50,000	3	Synthetic caulking and elastomer compounds.

This symposium may be termed a further examination of the possibilities of local petrochemical production. It may be termed a step in determination of relative net advantages or disadvantages to Alberta or to Canada through manufacture or export of raw materials. The problem to be solved, the decisions to be made, as presently assessed by officials of the Department of Industry and Development run somewhat as follows:

It is felt that the original owners of the natural resources, that is the people of this province, have a natural interest in endeavoring to maximize the benefits to be derived from the natural resources. They are looking for a fair compromise between getting for themselves the maximum local advantages -- that is, insisting that all processing to a completely finished state be done in Alberta -- or alternatively, allowing the oil development companies maximum and complete latitude in making decisions on a purely economic basis -- which might entail exports of all gas fractions, and no local processing or manufacturing whatever. To put it even more bluntly, we have to decide whether it is in our regional or Canadian interest to allow export of our liquid petroleum gases and of the condensates, total value of production of which in 1961 was close to $20 million. No further increments in value are possible if they are exported without further processing. We have to determine whether any additional petrochemical plants upgrading those gases into finished or semi-finished products would be of more immediate and long term benefit to our economy. We have to determine whether it is fairly and economically possible to have such plants built on Canadian soil.

One plant the size of Canadian Chemical Company, using only 3,000 barrels of gas-mix per day gives employment to nearly 800 persons and has an annual production of nearly $30,000,000 itself. In addition, due to its presence, due to the range of petrochemicals it produces, it has made possible, it has brought into the area such plants as Monsanto, Canadian Marietta, Fibreglas, Interprovincial, Naugatuck, and so on. Exports of petrochemical feedstocks bring no additional income to Alberta or Canada apart from pipeline tariff charges, and the labour income for the handful of men needed to maintain the pipeline.

Our Alberta petrochemical industry is still small. It only includes, strictly speaking, less than a dozen manufacturing plants. Yet it is giving a substantial boost to our provincial economy. I cannot resist the temptation, speaking as a statistician, to give you some comparative figures. In 1940 we had no petrochemical plants, which gave no employment, no labour income, no productive value; naturally. By 1947 we had one plant giving average employment to over 200 people, putting into circulation about $1 million in salaries and wages and contributing to our manufacturing volume. In 1961 the dozen petrochemical plants I have mentioned gave employment to 2,500 persons; put over $13 million into circulation as labour income; and produced a range of products valued at over $80 million.

To sum up now. We have tried briefly to outline the thread of the history of the gas industry in the province, and the growth in gas reserves to 1961. We have followed the evolution of government policy from initial control to prevent wastage, to preservation of adequate reserves for use in the province, to release for export of surplus gas, to the present day. We have noted the current benefits of the industry to the province in terms of employment, labour income, and value of manufactured products. We have drawn to your attention the question presently facing us -- as to how much more growth and diversification of the chemical industry in western Canada we can reasonably expect.

We hope that this symposium will provide some of the answers.

SOME RESINS FROM PRIMARY PETROCHEMICAL PRODUCTS

R. R. Demisch
Development Division, Imperial Oil Limited, Toronto, Ontario

Dr. Demisch born in Dresden, Germany, studied at the Universities of Dresden, Munich and Oxford, England. He obtained his Dr. of Engineering from Dresden. He worked several years with I.G.Farben Industry in Germany and Italy in technical service work, including co-ordinator for production for various chemicals. During the second half of the war he worked on explosive developments and was Manager of the TNT plant. Later he was with BASF Ludwigshafen as personal Technical Co-ordinator for Director of Application Department (AWETA), dealing especially with resins, plastics, and textiles. He has been in Canada since 1953 and is at present Supervisor Market Development and Technical Service, Chemical Products Department of Imperial Oil Limited, Toronto, Ontario.

A major portion of the huge and ever growing volume of petrochemical products finds its way into polymeric materials of one kind or another.

Under the term polymers we classify first, the very high molecular weight polymers, the elastomers and plastics, such as synthetic rubbers, polyethylene, polypropylene, nylon, polyvinyl chloride and plastics from polyesters; secondly, the relatively low molecular weight polymers, frequently called resins, which are used mainly in coatings, reinforced laminates, impregnations, moldings, etc.; thirdly, the group of dimers and trimers of some of the smallest unsaturated units of organic chemistry such as propylene or butylene.

In this paper I shall limit myself to some interesting low molecular weight polymer specimens of the resin group which are derived from primary petrochemical products, butadiene and styrene. You may say: "Butadiene-sytrene copolymers, aren't they 'old hat'?" Well, rubbers made from these two monomers have been known for approximately one generation. After the war, aqueous dispersions of butadiene-styrene copolymers appeared on the market. They were used successfully for coating purposes and therefore became widely known.

Today, I am presenting you with details of a relatively recent development made by Esso Research and Engineering Company in which both of the monomers mentioned are joined together in an interesting and different way, which provides us with a series of products with unique application properties. I am talking about Buton Resins*.

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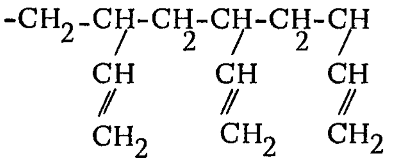
* Trademark of Enjay Chemical Company

As you know, low molecular weight polymers are more suitable for organic coatings than high molecular weight ones, since they are much more soluble in solvents and permit a high NVM content at a sprayable viscosity. Formerly, the surface coatings industry was attracted by the remarkable properties of polystyrene: its great resistance to water and chemicals, its excellent stability to light and its outstanding electrical insulation properties. However, they had to drop this product as a coatings resin because of its brittleness and the unavoidable thread formation during spraying, even in very dilute solutions. In order to develop coatings with some of the exceptional properties of polystyrene, the resin research chemists tried to improve the deficiencies of this polymer (a) by lowering the molecular weight and (b) by modifying it with other monomers.

With regard to the proper selection of a monomer for modifying the styrene, butadiene proved to be the most suitable one because it could react in two ways -- either as a vinyl ethylene in a 1.2 polymerization or as a butene-2 with two free valences in 1 and 4 position with provide for a 1,4 polymerization -- depending on the catalyst being used in each case.



$-CH_2-CH(CH{=}CH_2)-CH_2-CH(CH{=}CH_2)-CH_2-CH(CH{=}CH_2)$

1.2 Polymerization

$-CH_2-CH=CH-CH_2-CH-CH=CH-CH_2-$ 1,4 Polymerization

BUTADIENE POLYMERIZATION

In most known commercial syntheses, the 1,4 polymerization is the desirable one. Very long chains can be formed that way and reactive double bonds are provided for in the final polymer which can be crosslinked. Catalysts for this type of reactions are sodium amide or alkaline potassium persulphate or a peroxamine redox system, as is being used for SBR or cold rubber. Esso Research found that by using a specific catalyst and by changing the butadiene-styrene ratio, a new type of polymer structure can be obtained, an elementary unit which is shown in Figure 1.

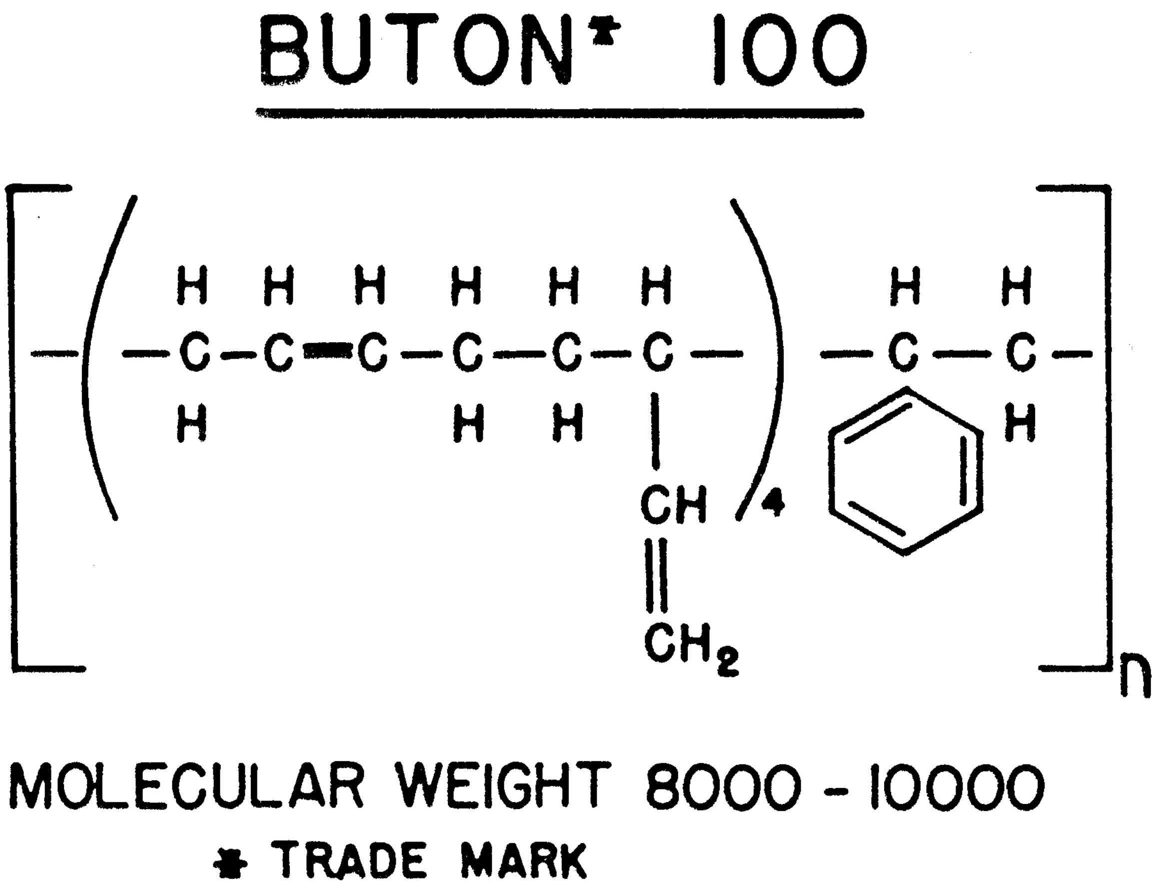


FIGURE 1. Buton 100 Molecule

This is the structure of Buton 100, a name for this particular copolymer which is made with 8 mol. of butadiene and 1 mol. of styrene (80 wt. % butadiene plus 20 wt. % styrene).

It can be seen that only 50% of the butadiene has reacted in 1,4 position to form the well known long chain of conventional SBR rubber molecules. Another 50%, however, has reacted in the 1,2 position.

This is of great importance. It means that in addition to the necessary carbon chains, we have free vinyl groups attached to the original chain. These free vinyl groups are naturally,excellently suited for further polymerization reactions. Now it is easy to visualize this complex called Buton 100 as a new vinyl monomer which can undergo the well known vinyl resin polymerization reactions, such as the forming of thread-like molecules and films on any given surface. The complexity of this new monomer, of course, provides for plenty of crosslinking opportunities, which means, in practical terms, a much stronger film as compared with the old polystyrene film and in this case also a highly flexible film. In addition, this particular structure also explains the advantage which the Buton Resins have over other vinyl resin vehicles. They are able to react in three ways instead of only one:

1. They can polymerize with themselves, especially at elevated temperatures.
2. They can act as an unsaturated drying oil by adding oxygen with conventional driers.
3. They can crosslink with themselves or with other vinyl monomers by means of an organic peroxide catalyst.

Therefore, these resins are suitable not only as paint vehicles but also for the growing market for laminations, moldings and glass-reinforced plastics.

TABLE 1. Typical Inspection Numbers of Buton 100, Buton A500, Buton 200, Buton 300

	Buton 100	Buton A500	Buton 200	Buton 300
	non polar	non polar	polar	polar
Molecular Weight	Approx. 8000	Approx. 9000	Approx. 8000	Approx. 8000
Oxygen content	0	0	10	16
Acid number	0	0	20	30
Hydroxyl number	0	0	100	150
Iodine value	330	330	270	210
Non volatile content	100%	100%	50%	45%
Viscosity, poises after Brookfield	3300	4600	-	-

As you can see from this Table 1, Buton 100 and Buton A500 are practically identical. Both are products without any polarity in the molecule.

The A500 type has a somewhat higher molecular weight range than the Buton 100. This is intentionally so. As explained above, Buton 100 must be applied in solvent solution for coatings; therefore, the molecular weight must be low. However, Buton A500 is used without any solvent. It is blended only with other vinyl monomers, such as vinyl toluene, divinyl benzene, methyl methacrylate and other vinyl or allyl compounds as a base stock for moldings and laminates. These are applications for which it is desirable to have molecules as large as possible for a smooth application technique and optimum properties.

For the coating applications of the copolymer, the structure of Buton 100 provides for a significant difference and variety of application possibilities as compared with most of the other known paint vehicles.

If a drying oil is treated in the presence of, for instance, naphthenate paint driers, it adds oxygen -- and the more oxygen added, the higher the curing temperature rises -- and very soon the resin formed becomes very brittle and loses its surface adhesion. In practical terms, it is over-cured. This is not so with Buton 100. If you increase the curing temperature of any Buton coating, it does not become brittle -- on the contrary it becomes more flexible!! This amazing behaviour is easily explained by the carbon-carbon crosslinking action at the highly reactive double bonds in Buton resins.

The practical result: coatings with such types of butadiene-styrene copolymers are more resistant to elevated surface temperature than any other conventional resins on the market except the silicones. This feature allowed the introduction of new techniques in surface coatings:

(a) The flame curing technique.

(b) The application on very hot metal surfaces (up to 500°F.).

(c) The flame spraying technique. Buton formulations with light solvents can be sprayed, for example through a so-called Wolf gun on a preheated surface. To keep this surface hot and to speed up the resin cure at the same time, the solvent of the paint is ignited and burns off during the spraying process. Well cured and faultless films can be obtained by this technique. For general use, however, the flame spray gun has to be developed further.

As indicated above, the coatings obtained by any one of the described techniques are highly resistant to corrosion and chemicals. In addition, they provide good electrical insulation and have a very low abrasion coefficient.

The Buton 200 and Buton 300 are modified Buton 100 in which polar hydroxyl and carboxy groups have been introduced, making these resins compatible with many other resins commonly used for protective coatings which are of a polar nature, such as nitrocellulose, polyvinyl chloride, alkyds, acrylics, etc. It should be noted that these modifications of Buton 100 did not detract from its desirable properties.

Table 2. Compatibility of Buton 200 Resins

Modifier	Weight per cent Buton		
	25%	50 %	75 %
Short oil alkyd	C	C	C
Medium oil alkyd	C	C	C
Liquid epoxy resin	H	C	C
Nitrocellulose RS 1/2 second in MEK	SH	SH	SH
Urea	C	C	C
Melamine	C	C	C
Vinyl - VAGH	SH	I	I

C - Compatible
SH - Slight Haze
H - Haze
I - Incompatible

Table 3. Compatibility of Buton 300 Resins

Modifier	Weight per cent Buton		
	25%	50 %	75 %
Short oil alkyd	C	C	C
Medium oil alkyd	I	H	C
Liquid epoxy resin	H	SH	C
Nitrocellulose RS 1/2 second in MEK	SH	C	C
Urea	C	C	C
Melamine	C	C	C
Vinyl- VAGH	C	C	I

C - Compatible
SH - Slight Haze
H - Haze
I - Incompatible

This compatibility is a very useful feature of Buton 200 and 300 (note Table 2 and 3), because by blending such Buton Resins with another conventional vehicle, it is possible to improve the deficiencies of the latter considerably, especially their resistance to water, detergents and chemicals. Hand in hand with adding Buton Resins, a better adhesion of the original vehicle on the various surfaces is obtained - as well as an often improved abrasion resistance.

Because of its nature, Buton 100 must be applied alone for paint formulations. It cannot be blended with other paint resins. However, if you recall my statements earlier, Buton 100 and, of course, Buton A500 are also well compatible with other hydrocarbon products, of which for practical purposes, other vinyl groups containing monomers are particularly interesting. Such blends can be easily copolymerized and cured after adding peroxide catalysts, for instance, dicumyl peroxide and ditertiary butyl peroxide at temperatures of not below 300°F.

The excellent properties of such copolymers lead us into a new area of applications for these resins, namely laminations, moldings, and glass reinforced plastic pipe.

Table 4. Viscosity of Buton A500/Vinyl Toluene Blends

Buton A500	Vinyl Toluene	Viscosity Brookfield (Poise)
100	-	4600
80	20	41.8
70	30	9.3
60	40	3.0
50	50	1.0

For impregnating glass fibers or for press molded products with quartz fillers as reinforcement, the ratio of Buton A500 to monomer should be 60:40 or 50:50. At these concentrations, the blend has its greatest reactivity and the cured articles made with these blends show maximum mechanical properties.

It is quite noticeable in Table 4 how the original viscosity of Buton A500 is reduced by the monomer. This is highly desirable in order to make the resin penetrate as completely as possible between the single fine glass filaments or quartz particles of the reinforcing material. In order to achieve bonding of the resin system with the glass itself, the addition of 0.5% - 0.75% of the total resin weight of a vinyl silane ester is required.

This bond between resin and glass provides for good strength of the finished article and protects against any possible loss of strength of the sensitive glass during the manufacturing process and service.

Table 5. Typical Wet Lay-up Formulation

Resin blend, parts by weight:

Buton A-500	60
Vinyl Toluene	40
Divinyl Benzene	4
Dicumyl Peroxide	2
Ditertiary Butyl Peroxide	2
Vinyl Silane A-172	0.5

Plies of 181 Glass Cloth:

A-172 finish	14

Cure Schedule:

Press moulded 40 minutes @ 154°C., 140 p.s.i.
Post cured two hours @ 177°C., no pressure

Table 5 shows a typical glass reinforced resin lamination formulation. We have the described 60:40 ratio of Buton A500 and vinyl-toluene. Some divinyl benzene has been added as a third monomer for improved crosslinking and as catalysts the two peroxides, dicumyl peroxide and ditertiary butyl peroxide, plus the vinyl silane ester for the bond with the glass or quartz reinforcement.

For the glass reinforcement, usually rovings, filaments and fabrics of a borosilicate type of glass, the so-called E-glass, are used. This material has an exceptionally high tensile strength. The diameter of each filament is 2/10,000 inch. In other cases, for instance, for panels, silica or quartz powder is a very effective reinforcing material.

The curing can be done either in a one or in a two step operation. To obtain premium quality a two step cure is conducted as follows:

(a) The article formed with resin impregnated glass is first prepolymerized to a so-called B-stage by press molding it at a temperature lower than that required for the final cure. This step is necessary to relieve the main part of inner tensions in such an article which are caused by the natural shrinkage of the resin during its cure. A fully cured article shrinks 8 vol. % and during this prepolymerization step a material is obtained which will shrink only 2% - 2 1/2% by being fully cured in step(b).

(b) The final cure is being done by heating up the article cured to the B-stage for a further time at a temperature around 30° - 50°F. higher than before. The shrinkage which occurs during this step is so low that it should not cause life shortening inner stresses if the first stage has been done properly.

It is believed that the recent development of glass reinforced Buton resin pipe is an important novelty, particularly for your area. (See Figure 2).

This is a piece of glass reinforced pipe made with Buton A500. Spiral Glass Pipe Co., Old Bridge, New Jersey, has prepared experimental quantities of this type.

This pipe, especially when produced later with larger diameters, should find its principal use in the oil and chemical industries.

Table 6 summarizes the reasons why a good future is predicted for this pipe.

Table 6. Advantages of Glass Reinforced Plastic Pipe

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1. Corrosion resistance
2. Non-contamination of product
3. Light weight
4. Improved flow characteristics
5. Low paraffin deposition
6. Low heat transfer
7. High strength

It is obvious that corrosion resistance must be outstanding due to the nonpolar hydrocarbon nature of the resin part.

Nevertheless, it may interest you to know that a corrosive agent also exists for glass reinforced Buton pipe: distilled water!! Fortunately, salt water is much more innocuous! Water will not attack the resin bond but it will actually dissolve the glass reinforcement. Since the surface area of the glass is so great as compared to its volume, even minute quantities of water cause great harm if you allow them to penetrate microscopic crevices in the low modulus resin matrix. Unless proper precautions are taken, these crevices will appear, especially during aging. However, this deficiency has already been overcome, as you can see in Figure 2.

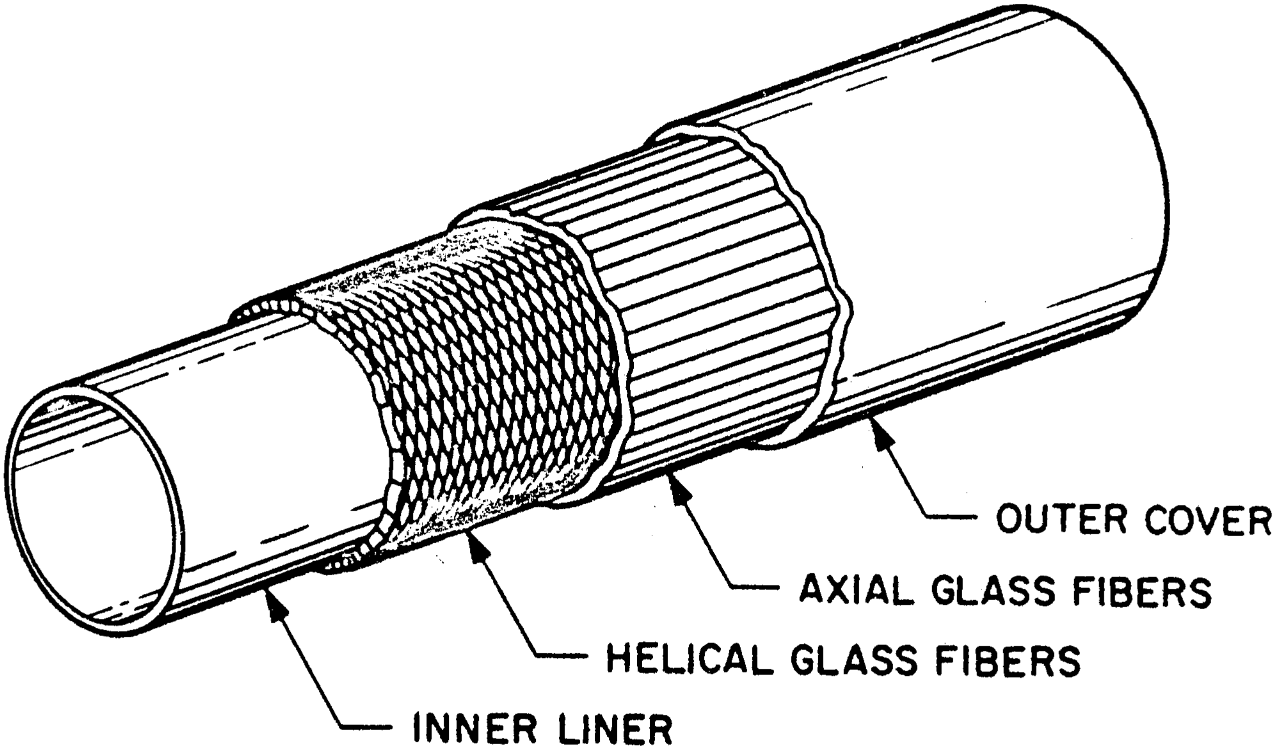

FIGURE 2. Typical Glass-reinforced Plastic Pipe

To protect the glass resin system, especially to prevent "weeping" through the pipe wall at elevated internal pressure, a chemically resistant inner liner has been added to the pipe which has a lower gas and vapor permeability than the resin matrix. It also insures a smooth, glossy inner pipe surface. This inner liner consists either of a carbon black filled, crosslinked polyethylene film - especially for transporting chemicals - or of a liner developed by Esso Research on the basis of an uncured high acrylonitrile containing butadiene rubber blended with polyvinyl chloride and carbon black - especially for transporting hydrocarbons. During the curing process, both liners crosslink with the resinous system and therefore develop a very strong bond with it.

The outer cover consists either of a polyvinyl material, to provide for an attractive exterior, or of the above mentioned ABR, PVC foil - especially if the pipe is used underground or in rather corrosive surroundings. Otherwise, it protects the glass resin system against external mechanical damage during shipping or installing, also, against UV light and other weather influences.

Table 7. Chemical Resistance of Polyethylene Liner

Samples of liner cured and immersed in test liquid at 93°C. for 90 days

Test liquid	Tensile strength retained, %	Elongation retained, %
Acetone*	99	100
Ammonia, 20%	97	67
Aqua Regia*	82	100
Benzene*	72	0
Methyl Ethyl Ketone*	89	100
Phenol	99	50
Triethanolamine	108	17

* Tested at room temperature

Table 8. Chemical Resistance of ABR-PVC Liner

Samples of liner cured and immersed in test liquid at 93°C. for 90 days

Test liquid	Tensile strength retained, %	Elongation retained, %
Sea water	93	60
Sulphuric acid, 10%	85	60
Formalin, 37%	98	40
Crude Oil	114	82
Gasoline - Esso Extra*	70	120
Kerosine	107	63
Toluene	45	100

* Tested at room temperature

Tables 7 and 8 show a comparison of the chemical resistance of liners. The second merit of such pipes, non-contamination of transported product, is self-explanatory. The weight of such pipes is (at 2" diameter width) 0.71 pounds per foot. Its specific gravity is 1.74. 22% of the pipe weight is resin, 58% is glass fiber and 20% is liners. The specific gravity of reinforced Buton A500 pipe compares with other materials as shown in Table 9.

Table 9. Specific Gravity and Strength of Some Piping Materials

	Spec. Gravity	Hoop Tensile Strength (Burst Test)
Buton/Vinyl Toluene Pipe	1.74	Up to 60,000 p.s.i.
Hard SBR Rubber	1.35	9,000 p.s.i.
Aluminum	2.7	14,000 p.s.i.
Carbon Steel	7.8	48,000 p.s.i.
Stainless Steel	8.0	75,000 p.s.i.
Copper (seamless)	8.9	30,000 p.s.i.

Improved flow characteristics are the next positive feature. The William-Hagen flow coefficient is in the range of 145-150, whereas steel has only 130. This will yield greater flow through plastic pipe than through steel pipe under the same conditions. In addition, it has to be considered that the steel coefficient reduces with time to 90. The plastics pipe coefficient remains fairly unchanged.

Almost no wax deposits occur on the walls of plastic pipe fabricated with Butons. In oil fields, crude steel pipes have to be cleaned at regular intervals because of wax clogging. The low heat transfer characteristics of plastics are well known. The armed forces, especially in the U.S.,are using reinforced plastics, for instance, for rocket cones. Skin temperatures can go up to thousands of degrees, while the interior remains relatively cool. It is obvious that the low heat transfer is an excellent feature in chemical plants for transporting hot liquids. With regard to the strength of reinforced plastic pipes, very much depends on the care with which such a pipe is manufactured. Additional development work needs to be done on this aspect.

For the time being, for continuous high pressure operation, only a fraction of the original burst strength can be permitted for safety reasons - especially at elevated temperatures. It is expected that this can be improved by future development. However, in the meantime, this should not discourage anyone from using such pipe. As a rough estimate the cost of reinforced plastic pipe amounts to approximately 4 1/2 times that of a comparable steel pipe at the present time. The price of corrosion resistant pipe, for instance, from stainless steel or copper alloys, goes up to 20 times the comparable steel pipe price. The low transportation and installation cost (Figure 3) of reinforced plastic pipe, however, compensates in part for its higher price in comparison with the average steel pipe.

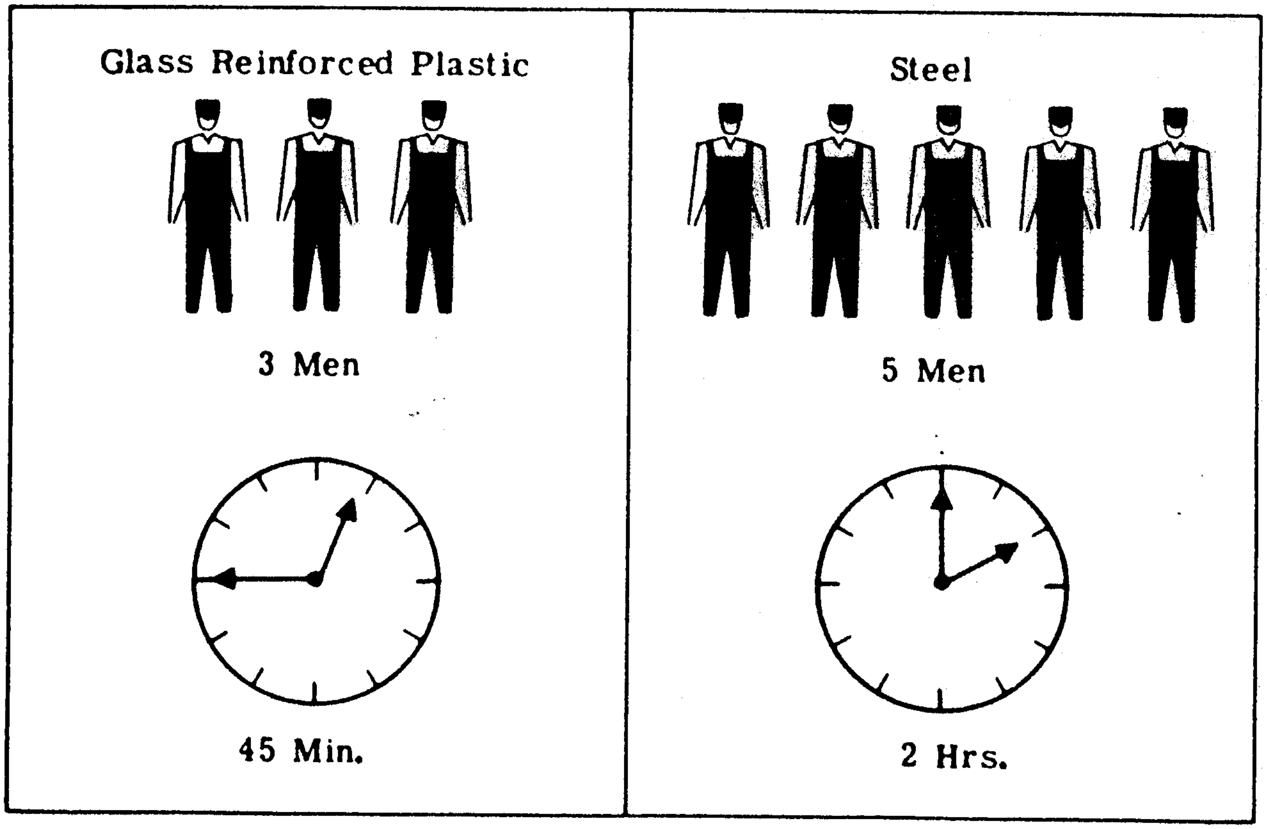

FIGURE 3. Ditching 500 Feet of 2-Inch Diameter Pipe

SUMMARY

The time available today has not permitted me to do more than scratch the surface of the many interesting possibilities for the practical application of these new type of butadiene-styrene copolymers. The petrochemical industry offers many dienes like butadiene and monomers containing vinyl groups. Therefore possibilities for further developments are legion.

The strides which the petrochemical industry has made in the past can only be maintained in the future if we promote extensive research work to find new chemical reactions. We must also proceed with very detailed development of application possibilities. A small example of the necessary attention to detail in order to achieve this goal has been outlined in this presentation.

DISCUSSION

Mr.J. G. Light, Texaco Canada Ltd., Montreal, Quebec: How does this material stand up under the effect of water hammer, and temperatures of 0° to -40°F?

Dr. R.R. Demisch, Imperial Oil Limited, Toronto, Ontario: Well, it is supposed to stand up to minus 50°F. For the time being I would not suggest it. It is not too flexible and this is the difficulty. The pipe may not break but the joints may fail.

THE ATTITUDE OF ALBERTA'S GOVERNMENT TOWARDS THE DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY

Hon. A. R. Patrick
Minister, Department of Industry and Development

On behalf of my Government I wish to offer a most sincere commendation to the Chemical Institute of Canada and to the members of the Research Council of Alberta for undertaking this symposium for the purpose of stimulating additional interest in the further development of the Petrochemical Industry in Alberta. My optimism for successful outcomes from it is based upon a very early assessment of the success of its predecessor, the Symposium on Iron and Steel. The past few months of rapid-fire development which includes R-N testing, construction of a special laboratory at the Council, the Page Hersey expansion at Camrose, Stelco's move into Alberta, Dominion Bridge and ACF Industries' announced plant for Calgary last week, certainly give me ample reason for such optimism and appreciation.

If the timing was excellent for that symposium then, surely, it is equally as good, or even better, for this one. Last year's most significant development in this province and certainly one of the greatest milestones in the history of Alberta, past or future, was the construction of a series of multi-million dollar gas processing plants spotting the province from one end to the other. It was the development we had looked forward to. Now it has happened. Suddenly we are faced with a huge and valuable source of raw materials for one of the youngest, yet already one of the greatest industries of modern times -- THE PETROCHEMICAL INDUSTRY.

I have been asked to spell out for you today the Government's attitude towards the development of the petrochemical industry. To do so, I must begin with a general statement to the effect that the Government is intensely interested in seeing a great petrochemical industry develop in the province, as a very important part of an over-all industrialization of Alberta. Already, the people of Alberta have had ample proof of the value of economic diversification as compared with the single-agricultural economy which left us so vulnerable to disaster in the dirty thirties. Last week's national statistics show us to be the fastest growing province, percentagewise, in Canada, and the province least affected by the recent recession. In fact, nearly every community in Alberta is now almost feverishly and anxiously hoping to see industry in its midst in the near future.

Naturally, then, the Provincial Government has been working overtime to improve and refine Alberta's industrial climate. In general, the various Departments of Government - Municipal Affairs, Mines & Minerals, Lands & Forests, Highways, and Health, and the Department of Labour - are concentrating on their programs toward this end. In particular, we have gone all out through the Department of Industry and Development to promote industrialization. By using the services of the Marketing Board, the Statistics Bureau, the Publications Branch, the Power Commission, the Co-operatives Guarantee Act, the "Buy Alberta" campaign, Alberta House and, last but by no means least, the industrial section of the Research Council, we are witnessing industry developing in the province and industry coming to the province by branch development or by license. Without sacrificing our principles, which oppose subsidization and tax concessions, our industrialization thus far is based on sound foundations of a free enterprise climate.

So much for general attitude. What about the petrochemical industry and this suddenly great additional supply of raw material? I note from the program that you have been made thoroughly familiar with the history of petrochemical development in Alberta up to the present. I'm sure you will agree that the significant aspect of this development is that the availability of the raw material has been completely tied to natural gas discovery which, in turn, has been so closely associated with and dependent upon oil exploration. The unique aspect comes from the situation of having a raw material becoming available that cannot be easily left in the status of a resource for future development. Now that natural gas is on its way to export markets, the petrochemical raw materials in the form of liquid petroleum gases are about to stare us in the face in ever increasing quantities. It is at this point that government attitude and policy become extremely important and critical.

Up the road, through the good offices of the Oil & Gas Conservation Board, the Government was made well aware of what the situation could be at this point down the road, should certain decisions, nationally and internationally be reached on gas export.

Little difficulty was experienced in carrying the public's judgment on the need for conservation methods on prohibition of flaring gas, on flow controls for maximum production, on spacing, on unitization and on the need to market all surplus oil. But it was a far more difficult proposition when it came to gas export. Not until there was definite assurance of adequate proven gas reserves for the present and future, both for domestic and commercial fuel, plus the assurance of extraction of L.P.G.'s from exported gas, was the public ready to go along. Unfortunately, this latter requirement, which is an engineering necessity, has been misinterpreted by some to mean prohibition of exportation of L.P.G.'s.

Now that the L.P.G.'s are being extracted in ever increasing quantities, which means that we have reached such a critical stage in their industrial use, let us look at the complexity of the problem which the government must face. Comparisons are being made between gas fuel costs in remote communities in the province and the densely populated areas in other parts of Canada; also between domestic costs and industrial costs of fuel in the same areas.

We know that a large portion of the public is failing to comprehend all the factors that enter into costs of consumer gas. It is not fully realized, for example, that many remote or sparsely populated communities never would have enjoyed the advantages of low cost gas fuel but for the grid system established to collect the gas for export. Many Albertans, including most farmers, who cannot hope to be served from gas lines, and, therefore, must rely on propane for domestic use, fail to appreciate that stable prices and supply is only possible as a result of export of natural gas. Those people enjoying extremely low costs of natural gas in densely populated areas, get a portion of this advantage as a result of the large quantities consumed by adjacent industry.

Thus you can see the difficulties a Government will encounter when it comes to convince the public that the international petrochemical picture can change to the point where the raw materials we possess are barely competitive with newly found refinery derivatives which are adjacent to markets, thus saving the long distance freight charge disadvantage; also that the storage of these materials poses a myriad of economic and practical problems. It is very difficult to convince the public that prices of L.P.G.'s must be kept at a minimum if we hope to attract petrochemical industry to the province and, most important of all, that if a petrochemical industry is forced to close down because the public is not willing to allow any leverage on its price advantage, then the low price advantage itself is completely lost to the domestic consumer when the plant closes and stops consuming these large quantities of gas.

Add to all this the unwillingness of the public to accept in its judgment of domestic costs the indirect increments that accrue to the community as a result of a new petrochemical industry in its midst and you can see some of the problems facing a Government in getting Mr. Domestic Consumer convinced of the value of more petrochemical industry and that he has a tiny part to play.

Perhaps the best way to illustrate or describe the Government's attitude towards the development of the petrochemical industry is to point to the decisions, step by step, that the Alberta Government has made in the development of the oil and gas industry since the establishment of the Oil and Gas Conservation Board in 1938. These policies will illustrate to you, our determination to get a maximum use and development of these natural resources. So far as returns to government coffers are concerned, we naturally want the best returns possible to the original owners of these resources - the people. But at the same time we have always demonstrated a long-term outlook to make abundantly sure "that we don't kill the goose that lays the golden egg". Nor will we be stampeded into a quick profit that could come from exporting this now-available, difficult-to-store, raw material so long as it is possible to have it used in the province where the really important increments will come from having thousands of people enrich the province through the increments of full employment.

It isn't a matter of deciding which we should put first -- people or industry. Rather, it is a matter of determining the complex advantages that will give the best overall and long range picture.

PRIMARY PETROCHEMICALS - PAST, PRESENT AND FUTURE

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J. L. Porter was born in Hamilton, Ontario. He graduated from Virginia Polytechnic Institute in chemical engineering. He joined the British American Oil Company Limited in 1934 as a chemist and served in various refineries from Calgary to Montreal. In 1948, he was transferred to the Head Office in Toronto as a process engineer. Then in 1959 he became petrochemical adviser to management, the position he presently holds.

INTRODUCTION

The word petrochemical has had many definitions, but primary petrochemicals as a special class requires further definition. In this paper, primary petrochemicals will be confined to two groups (A) those which exist in natural gas, condensates, and crude oil, or which are found in the products of the average crude refining, natural gasoline, or natural gas plant (B) such chemicals that can be obtained from these sources by a relatively simple operation. The operation can be thermal, catalytic or physical in nature, and usually generates a single major product, although in a few cases there may be several products.

Sulphur, by this definition, is a primary petrochemical when produced in gas plants and refineries. However, sulphur belongs in a class by itself and perhaps should be the subject of a separate discussion.

How important are these primary petrochemicals to our industrial and economic life? Since it is a well known fact that reliable chemical statistics for Canada have been difficult to obtain, the corresponding U.S. data may be more informative, bearing in mind that Canada produces a ratio of between one-tenth and one-twentieth of the U.S. output, on the average.

As shown in Table I, the leading primary petrochemical is ethylene, followed closely by benzene, and both are produced in greater quantities than are such commodities as copper, zinc and lead. Ethylene may even pass sulphur in the not too distant future.

History of Primary Petrochemicals

Organic chemical technology up to and during the first world war was based on vegetable, animal, and other carboniferous sources, such as coal. This included the production of acetylene from calcium carbide. But around 1920, considerable

Table I. COMPARATIVE U.S. PRODUCTION OF SEVERAL COMMODITIES

in billions of lbs.

Petroleum	700
Steel Ingots	200
All Chemicals	185
All Petrochemicals	60
Sulphur	11
Ammonia	10
Fibers, all types	7
Plastics and Resins	7
Ethylene	6
Benzene	4
Aluminum Ingot	4
Rubber, synthetic	3
Copper	3
Propylene	3
Butylene	3
Butadiene	2
Polyethylene	1.8
Zinc	1.6
Acetylene	1.3
Fibers, synthetic (ex rayon)	0.75
Lead	0.7
Naphthalene	0.65
Cyclohexane	0.43

Source - U.S. Govt. Statistics

attention was being given to the double-bonded hydrocarbons, such as ethylene, propylene and butylene, which were known to exist in the gas produced in the cracking of petroleum oils, which was just then coming into prominence.

It is stated that the conversion of propylene to isopropyl alcohol in 1919 marked the beginning of the as-yet-undefined petrochemical industry. The first pilot plant work was done at that time by Melco Chemical Company based on a laboratory study made by Berthelot in 1855. The synthesis used the reaction between sulfuric acid and propylene which is still the major process for the production of this alcohol. However, it should be noted that carbon black was made from natural gas as early as 1859 and that petroleum coke was an article of commerce before 1920.

The first petrochemicals in the 1920's were produced from relatively impure streams of hydrocarbons produced by thermal cracking of petroleum oils, although fractional distillation was used to separate the three member hydrocarbons from the four member compounds, and so on. In the case of ethylene and ethane, low temperature was used for the separation from propane-propylene mixtures. Using the same technique which made isopropyl alcohol, ethylene was converted to ethyl alcohol, and was reacted with hypochlorous acid to produce ethylene glycol and ethylene oxide. The same chemistry was applied to propylene, and subsequently to butylene, ending up in a series of derivatives, many of which were brand new.

There was a steady increase in the output of chemicals derived from ethylene and propylene, as shown in Table II. The data applies to only one firm and it must be realized that other companies were developing along the same lines simultaneously.

Table II. NUMBER OF COMPOUNDS MADE FROM
OLEFINS BY CARBIDE AND CARBON CHEMICALS CO.

Year	Derived from Ethylene	Derived from Propylene	Total
1926	5	2	7
1929	15	4	19
1934	35	15	50
1939	41	27	68

Source: The Petroleum Chemicals Industry (2nd Ed.) Goldstein.

Petrochemical growth accelerated rapidly from 1940 on, not only with respect to the diversity of products, but also from the standpoint of variety of feedstocks, new processes, and methods of separation. Propane and butane were directly oxidized to produce alcohols, ketones, aldehydes and acetates. Toluene and xylene were obtained from cracked and straight run petroleum naphthas by means of hydrotreating, azeotropic and extractive distillation, and other methods new to the petroleum industry. At the peak of the war, in 1944, 166 million gallons of toluene came from petroleum in the U.S., versus only 38 million from coke ovens. At the cessation of hostilities, production of toluene from petroleum dwindled to almost zero, but the 1944 ratio was reached again by 1958. Benzene was not made from petroleum until 1950, but since then has had an amazing growth rate.

Increasing requirements for olefins led to techniques for increasing the amount produced. To do this, severity of cracking was raised and also lighter feedstocks down to ethane and propane were utilized. Olefins were hydrated, chlorinated, oxidized and reacted with carbon monoxide and hydrogen. Dehydrogenation of butane was carried to the point where butadiene was the major product to make synthetic rubber during the war and afterwards.

Natural gas, and later petroleum liquids, began to displace coke and coke-oven gas for the production of hydrogen and carbon monoxide, and natural gas became the major raw material for methyl alcohol and ammonia. Gas also was cracked to yield acetylene, displacing the inorganic source, calcium carbide, to some extent.

New primary petrochemicals appeared as technology grew, with corresponding shifts in demands for such chemicals. Cyclohexane became the prime source for nylon, and finally naphthalene was produced commercially from petroleum.

These changes in technology and demands have caused most of the difficulty in making a clean separation between primary and secondary petrochemicals.

In the beginning, ethylene was a feedstock obtained from refinery gases and had a fuel value only, but today huge quantities of ethylene are produced from many sources and are sold as a definite chemical compound; thus ethylene glycol, at first a primary petrochemical, became a secondary chemical.

Cyclohexane is produced as a primary petrochemical, but is also made from benzene by hydrogenation and can therefore be of a secondary nature.

Primary Petrochemicals Today

What does the primary industry look like in 1962? Natural gas is used in large quantities to produce various mixtures of hydrogen, carbon monoxide, carbon dioxide and sometimes nitrogen. The technology for this purpose is in a state of flux. There are two major approaches for producing these synthesis gas mixtures. The first, as shown (Figure 1) is the steam-methane reaction which requires a catalyst, usually based on nickel. In this process, which is highly endothermic, methane and steam in the correct proportions are passed through a heated multi-tubular reactor packed with catalyst, at temperatures in the range of 1400° - 1800°F. In the early 1930's, the pressure in the tubes was near atmospheric because of limitations in the strength of the tubes at the elevated temperatures. Today, pressures of 200 - 300 psig are being used and should go even higher following advances in metallurgy. The outlet pressure is often important to further downstream processing and since gas is often available under considerable pressure, significant savings in operating cost can be obtained with the higher operating pressures.

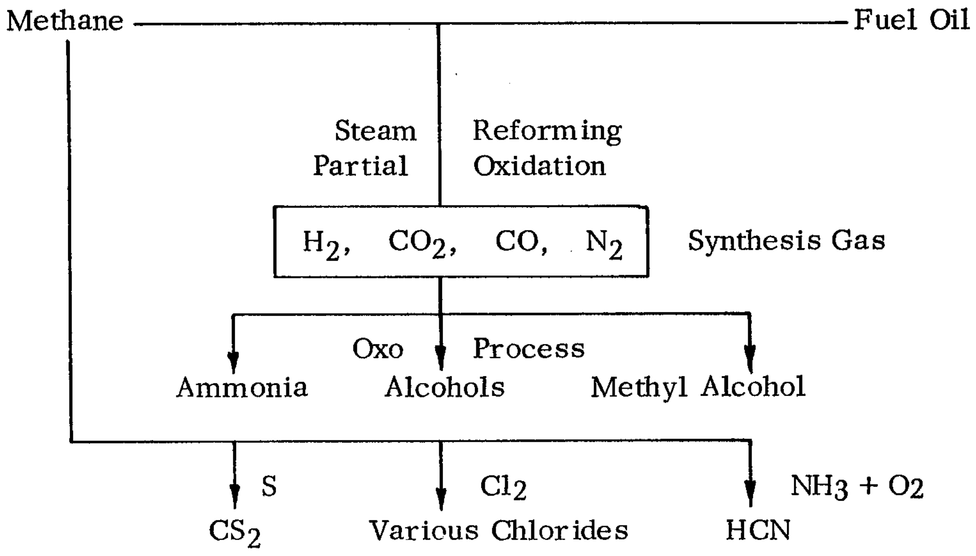

Figure 1.

The other major process does not necessarily require a catalyst. Heat is supplied to the reactor by burning a portion of the gas with oxygen or in some cases with air. Variations of this process can use fuel oils rather than gas for feedstock and in some designs, steam reforming is combined with partial oxidation to achieve the required end product. In most recent plant designs, the high temperature gaseous products are passed through steam generators to recover heat.

Relatively pure hydrogen can be obtained by the catalytic conversion of carbon monoxide in the synthesis gas to carbon dioxide, followed by removal of the carbon dioxide.

There are a number of uses for mixtures of carbon monoxide and hydrogen, as for example for conversion to methyl alcohol, and for the oxo process, in which an additional carbon atom can be added to an olefin to produce aldehydes and alcohols. Nitrogen and hydrogen mixtures are required to synthesize ammonia and with the addition of carbon dioxide, form urea. Carbon monoxide and carbon dioxide are both used to some extent as chemical reactants, and can be easily separated from the synthesis gas.

Direct oxidation of methane is not a commercially successful process, but methane reacted with sulphur forms carbon disulphide, widely used in the manufacture of rayon and to make carbon tetrachloride.

Methane can be chlorinated to produce all the possible derivatives from methyl chloride to carbon tetrachloride, including chloroform. The reaction is exothermic and is usually carried out around 750°F. By varying the ratio of reactants and recycling of the various product streams some degree of control can be exercised over the product distribution. Separation of the chlorides requires only normal fractional distillation procedures, but there is a corresponding volume of hydrochloric acid to be disposed of.

Methane when burned with ammonia and air under conditions of partial combustion at temperatures over 1800°F, and over a platinum catalyst, produces hydrogen cyanide. Since the cyanide is in a diluted phase, 6-7 1/2%, it is recovered by absorption in water, followed by stripping.

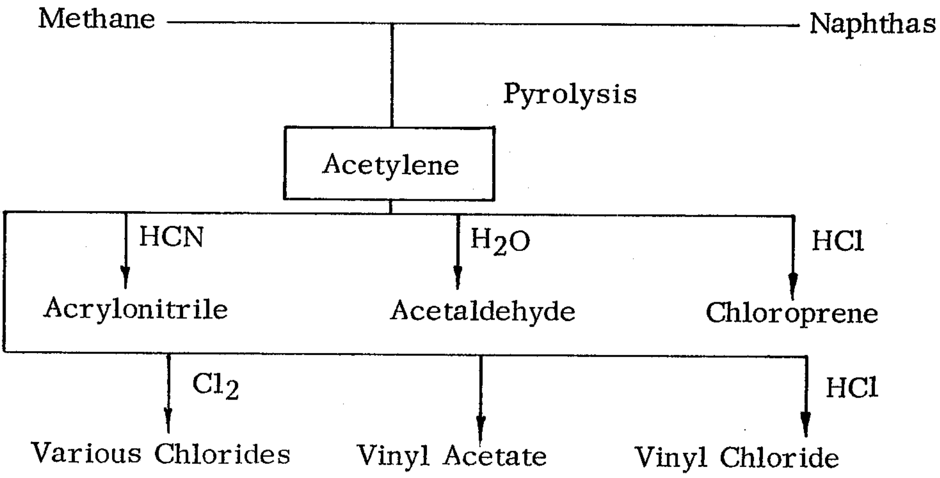

Figure 2.

Conversion of methane to acetylene as shown in Figure 2, commenced in the United States about 1952, and there are now several plants in operation. There are several thermal processes available and certainly in this area at least the results of research and development have been prolific. All processes are based on very rapid heating of the feed with oxygen, under conditions of partial combustion, maintaining the material at the high temperatures for a controlled but short time, followed by rapid cooling of the products to prevent further decomposition. Energy consumption is high. Temperatures in the reactor are over 2000°F. and residence time less than one one-hundredth of a second.

In some processes oxygen and gas are heated separately before mixing, while in others they are mixed beforehand. There are two-stage processes in which oxygen is heated by combustion with a minimum amount of fuel, and then natural gas is injected into the hot combustion gas. This procedure allows the use of fuel other than the reactant gas. In most processes, the residue gas contains large proportions of hydrogen, carbon monoxide and carbon dioxide, and thus can be used as synthesis gas.

There is one process using the regenerative furnace principle, wherein heat is stored up in a solid refractory mass by combustion of fuel with air, followed by transfer of the heat to natural gas. There is no large commercial installation of this type, however.

Production of acetylene by using the energy of an electric arc, or discharge, for decomposition of natural gas, has been used successfully but because of the cost of electricity, and for other reasons, is not widespread. However, one company in the United States announced recently that a commercial installation using electrical energy was to be installed by them.

The gaseous products from these processes contain 8 to 14% of acetylene along with many impurities. Extensive clean-up and separation facilities are required. Fine carbon particles and tars are removed first. Usually the acetylene is absorbed in a solvent, a variety of which can be used. In some cases two different solvents are utilized to remove methyl acetylene and other higher acetylenes selectively. It is in this area of separation that considerable plant investment is required and the displacement of calcium carbide as a source of acetylene has not been as rapid as it was once anticipated it would be.

Acetylene is used to manufacture vinyl chloride, vinyl acetate, acrylonitrile, acetaldehyde, tri and per chlorethylene and there is an expanding usage of this chemical. However, ethylene can be, and is being, used to produce many of the products made from acetylene. In Eastern Canada, Shawinigan Chemicals is building an ethylene plant for this specific purpose.

In all these high temperature processes it is often possible to use hydrocarbons heavier than methane for feedstock, as long as coking and other related problems can be solved.

If propane or butane for instance are used in some of the acetylene processes, ethylene will be produced co-currently. Ethylene itself is the primary petrochemical which is produced in the largest quantity, as shown in Table I.

Pyrolysis and dehydrogenation of ethane, propane, and heavier hydrocarbons are used to produce the large quantities of ethylene (Figure 3) consumed today, augmented by refinery off-gases, in many instances. Since the temperatures required are less than used for the production of acetylene, the feedstocks can be heated in tube stills to a temperature in the range of 1300° to 1500°F. Contact time is in the order of a few seconds at two to three atmospheres of pressure. Steam may be used to lower the partial pressure of the hydrocarbons and to reduce coke laydown. Other olefins, especially propylene, are produced simultaneously when using feedstocks heavier than ethane and the ratio of propylene to ethylene can be controlled to some extent. Contaminates such as acetylene and its derivatives must be removed from the gases, and rather elaborate fractionation and absorption techniques are required to separate the various components of the pyrolysis gas.

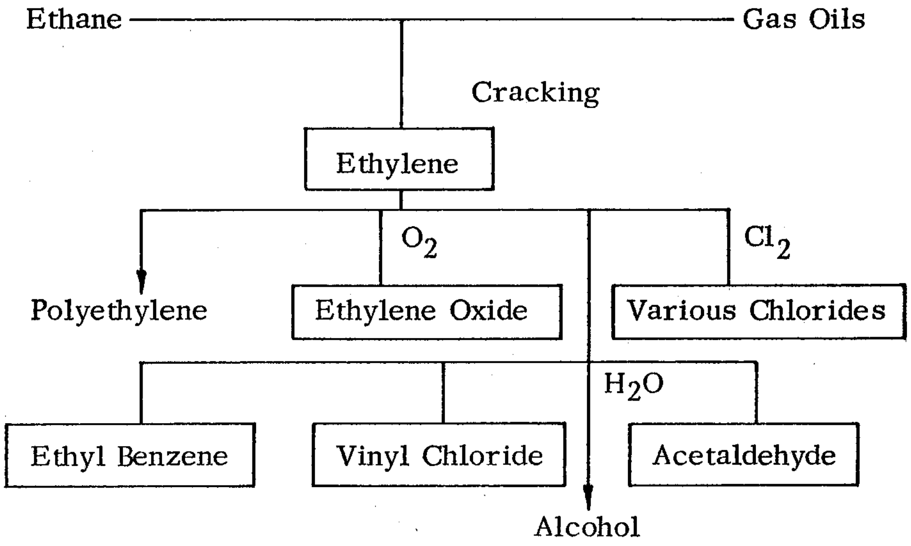

Figure 3.

The pressure on price has placed ethylene in a category where large plants must normally be built to obtain a reasonable return on investment. Latest plants announced in the United States are in the 400 to 500 million pound-per-year category and these plants will be using low priced propane and butane feedstocks. One of these plants could probably equal the total available capacity in Canada.

In Canada, Shawinigan Chemicals will convert ethylene to acetaldehyde by means of a direct oxidation process developed in Germany. A somewhat similar process is to be used in the United States by the Celanese Corporation, which company has been the pioneer in the direct oxidation of propane and butane to produce a great variety of chemicals, including acetic acid. A visit to the Edmonton plant of Canadian Chemical Company will show the complexity of equipment which is required to separate the many products of direct oxidation.

The bulk of the propylene used up to now came from refinery gases, since elaborate purification is not required for the manufacture of isopropyl alcohol, cumene or for detergent usage (dodecyl benzene) (Figure 4). However, polypropylene requires a very pure feedstock and propylene produced with ethylene will become more important because it will be available in large volumes which can be purified at less cost per lb.

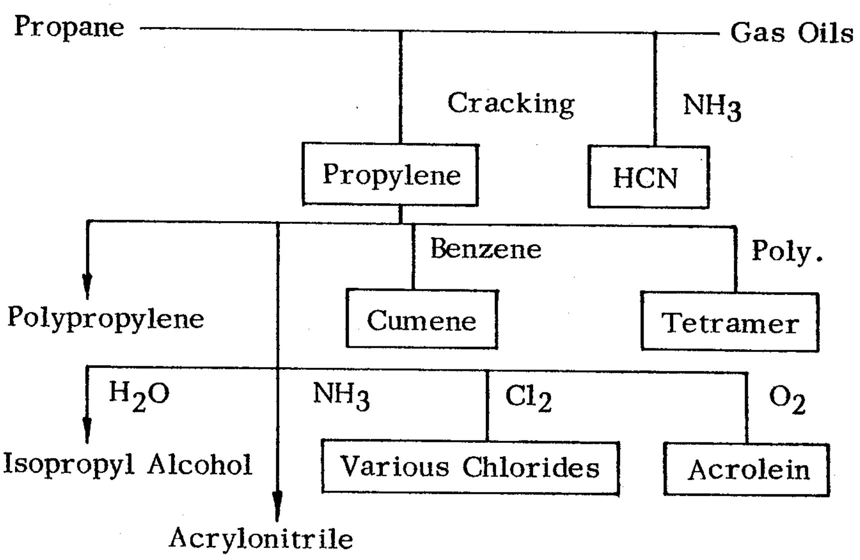

Figure 4.

Propylene can be chlorinated with further conversion to glycerol. Propylene oxide and propylene glycol are normally obtained through a chlorine derivative, although direct oxidation is claimed to be successful. The usual product obtained in the oxidation of propylene is acrolein, which can be converted to glycerol by a relatively new process, thus eliminating the consumption of chlorine.

A new process was introduced recently which reacts ammonia directly with propylene to form acrylonitrile, a building block for orlon and some synthetic rubbers.

Acrylonitrile has also been made from acetylene and hydrogen cyanide and can be made from acrolein, ammonia, and oxygen. The chemistry of the routes to various intermediates and end products becomes more and more intricate as the molecular weight of the feedstock increases.

A process for converting propane or other hydrocarbons directly to HCN is shown in Figure 4. This refers to Shawinigan Chemicals' new fluohmic process which utilizes an electrically heated and activated, fluidized bed of carbon in the reaction zone.

Butylene and isobutylene have been used in increasingly large quantities for the production of synthetic rubber. Both are obtained from refinery gases and ethylene plant gases. Butylene is the preferential feedstock to produce butadiene, the doubly unsaturated monomer used with styrene to make most of the synthetic rubber (Figure 5). Isobutylene is required for the manufacture of butyl rubber and is separated from the normal butylene by preferential absorption in sulfuric acid. Butadiene requirements are such that a large volume of normal butane is dehydrogenated through butylene to the diene using a chrome-alumina catalyst, with cyclic regeneration to remove carbon deposits. In another process, butylene is dehydrogenated over a calcium nickel phosphate catalyst with an excess of steam, also requiring cyclic regeneration. Normal butane is removed from the feed in this process by extractive distillation. The endothermic dehydrogenation of butane and butylene to butadiene requires temperatures in the range of 1000 to 1300°F., at low pressure, in some cases this being below atmospheric, and the reaction must be rapidly quenched.

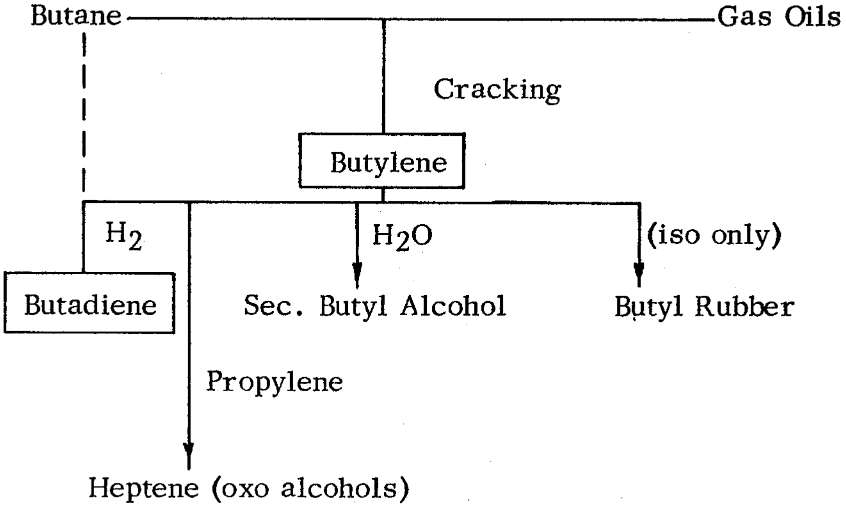

Figure 5.

Butadiene in the gross product from the reactors may amount to 9 to 16%, which must be recovered by extraction in a suitable solvent, usually copper ammonium acetate or furfural. Acetylene derivatives are removed by various methods, including absorption in solvents, or by selective hydrogenation.

Butadiene is also produced in cracking paraffins for the production of ethylene and propylene. It can be extracted by the same procedures used in the butane dehydrogenation plants.

Butylene and propylene together form a polymer, heptene, which is used in the oxo process to make iso octyl alcohol, and there are other uses of a minor nature.

New synthetic rubbers, sterospecific in nature, are being made from butadiene by polymerization. These and others like them are expected to replace natural rubber.

Higher olefins have been less significant in the petrochemical industry. However, isoprene, which is the basic component in natural rubber, is being polymerized to reproduce almost the exact pattern of the natural material. The product, polyisoprene, will compete with polybutadiene for this market.

Isoprene exists in small quantities in cracking plant gases and can be made from isopentane, using the same method which is satisfactory for the production of butadiene. However, the feed and product purification steps become more difficult.

There are several other methods for producing isoprene, from acetone and acetylene, from isobutylene and formaldehyde, and from propylene dimer. This rather complex chemistry may seem to run counter to the definition of primary petrochemicals, but postulated at the beginning of this paper isoprene belongs in this class as being in the same category as butadiene. It remains to be seen which of these processes, shown in Figures 6, 7, 8 and 9, will win out as the prime method for the production of isoprene.

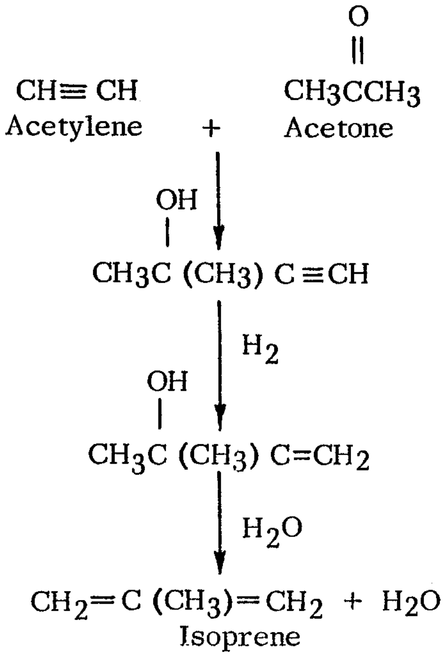

Figure 6.

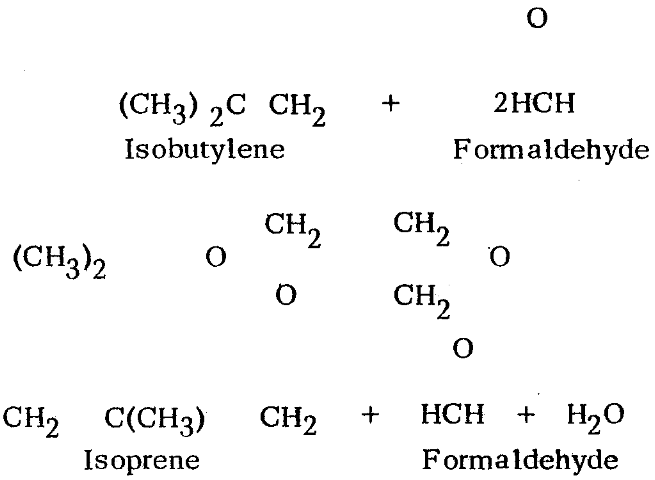

Figure 7.

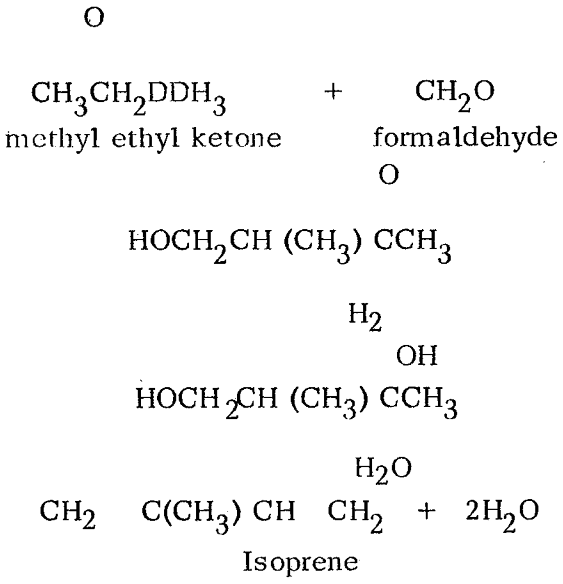

Figure 8.

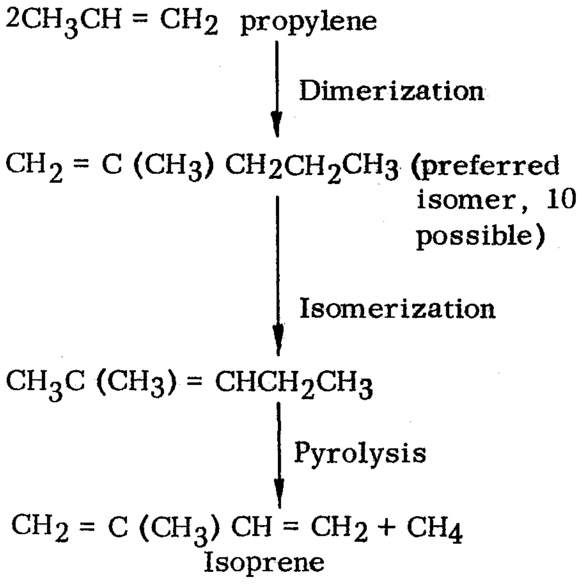

Figure 9.

The other major group of primary petrochemicals (Figure 10) includes the aromatics, benzene, toluene and xylene, and more recently naphthalene. Steel companies and operators of coke ovens dominated this market for many years until the advent of catalytic reforming processes, coupled with a satisfactory extraction procedure. Catalytic reforming was developed to produce high octane gasoline and one of its main features is the dehydrogenation of naphthalenes to the corresponding aromatics; cyclohexane to benzene, methyl cyclohexane to toluene, and so on. An extraction process using diethylene glycol, and more recently higher glycols, was developed which could produce very pure benzene, toluene and xylene from catalytic reformates, with high percentage of recovery. From 1950 on, many of these extraction plants under the name of Udex Units were installed.

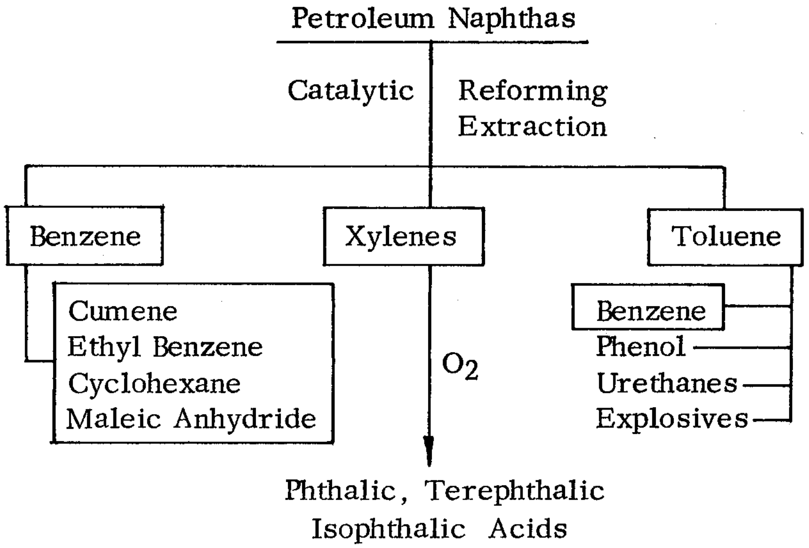

Figure 10.

There are four such units in Canada today, three of which went on stream in 1961. As a result of these plants, imports of benzene into Canada, which once amounted to almost as much as production, should cease. Instead there should be an export quantity equal to consumption. In the U.S. there has been a similar increase in capacity to produce petroleum benzene, as well as toluene and xylene. In addition to Udex extraction units, new hydrodealkylation processes were developed which can remove the methyl groups from toluene and xylene, thus converting the higher molecular weight aromatics to benzene. Some of these processes are catalytic, while others are thermal. In general, they operate in the range of between 1250 - 1400°F. at moderate pressures of less than 800 psig, and require considerable hydrogen partial pressure to prevent coking. The reaction is highly exothermic. One of these units was installed in Canada last year and another will be completed in 1962. A simple flow diagram of such a unit is shown in Figure 11.

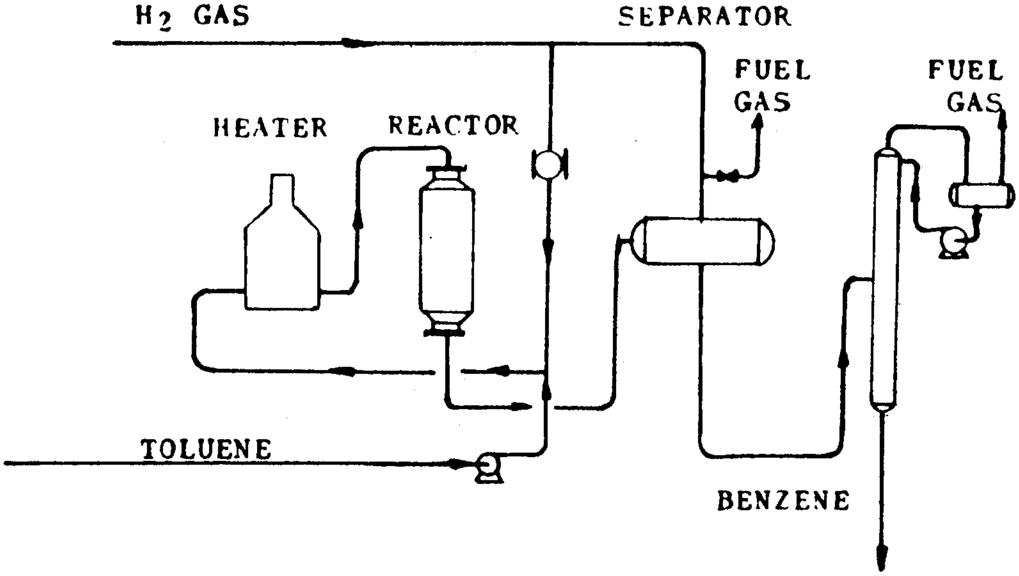

Figure 11.

This process has been extended to the fused ring compound, naphthalene. Catalytic reformates boiling between 400 and 500°F. often contain a high percentage of naphthalene and alkyl naphthalenes, along with alkyl benzenes. Hydrodealkylation of this material produces very pure naphthalene along with benzene. An alternate feedstock can be obtained from the light cracked fuel oil produced in the cracking of petroleum gas oils. In this case, it is usual to concentrate the aromatic constituents by solvent extraction.

The xylene mixture extracted from reformates contains all three isomers, as well as ethyl benzene. The ethyl benzene and ortho-xylene can be separated from the mixture by normal fractionation, although many trays and much reflux are required to obtain the purity desired. The meta and para isomers have been separated by fractional crystallization, but there is a new process available which utilizes clathration. Another approach has been to oxidize the mixed xylenes with subsequent separation of the anhydrides.

Since steel technology is shifting to fuel oil and gas for reduction of the iron ore, with relatively less consumption of coke, it is providential that petroleum aromatics became available in the quantity necessary to meet the demands of the chemical industry.

Most of the primary petrochemicals are produced in Canada, but as yet only ethylene, synthesis gas, and some propylene and butylene are utilized in Alberta.

The Future of Primary Petrochemicals

What do primary petrochemicals look like in the future, especially in Canada?

Export markets are disappearing, and Canadian demands are usually not large enough to support the size of plant deemed necessary in the U.S., which can produce a host of products ranging all the way from ethylene to naphthalene. They are trying to emulate the packing plants which claim they use all of the pig except the squeal.

We will have to be more adroit in employing our resources through the use of more advanced technology, by designing multi-purpose units, and by developing special situations, if we are to compete with these large plants. Another approach is the use of direct synthesis rather than going through several steps, each of which increases the cost of manufacture. An example of this is the production of acrylonitrile directly from propylene, or perhaps the Japanese process which uses photochemical energy to activate a reaction for conversion of cyclohexane to caprolactam (monomer for nylon 6).

Ethylene will continue to lead the field. It has been estimated that ethylene capacity in the U.S. may reach 10 billion pounds per year by 1970. Although consumption of propylene and butylene will increase at a faster rate, the gap between them and ethylene will not be closed. Aromatic chemicals will become more important now that the chemical industry has an assured source. Isoprene will be added to the large volume primary petrochemicals, and acetylene should better than hold its own against the inroads of ethylene because new products will be developed requiring acetylene as an intermediate.

The increasing demand for hydrogen in refinery processes should result in a cheaper process for the production of hydrogen. A number of R & D departments are working on this problem. There may be increasing use of radiation techniques for the conversion of chemicals. One close to commercialization is the conversion of ammonia to hydrazine in a nuclear reactor, and fixation of nitrogen is considered to be feasible. The many studies which are being carried on with plasma jets should result in chemical applications of this technique because of the abundance of free radicals produced in the ionizing regions of the jet. Fuel cells also may produce chemicals, along with electricity.

The chemical industry in North America has been undergoing a revolution over the past decade, due almost entirely to the availability of petrochemicals in increasingly large volumes and variety. New companies entered the field, while there were mergers and acquisitions by the score. Changes in technology and new product development shifted emphasis from one process or product to other processes or products, almost as rapidly as the pattern changes in a kaleidoscope. This phase is not over, and there are exciting times ahead. There should be no lack of challenge, or no stagnation, for either the neophyte or the old hand in Canada's petrochemical industry, or should one say chemical industry, since the difference is fast disappearing, if in fact it exists at all.

DISCUSSION

Dr. R. M. O'Brien, University of Alberta, Edmonton, Alberta: I would like to ask Mr. Porter a question which occurred to me during his interesting address. This was, he mentioned, a new process called clathration for the separation of some of the aromatics. I wonder whether he would care to outline whether this is at the moment on-stream or is it a lab process yet?

Mr. J. L. Porter, British American Oil Co. Ltd., Toronto, Ontario: I understand that the process was commercially utilized by Cosden (Petroleum Corporation, Big Spring, Texas).

Dr. R. M. O'Brien: I wonder if I could ask you to explain, to some of the people who might not know, what clathration is. It is one of my old interests, which is why I am so surprised to see it. It was discovered about 1948 by Powell, at Oxford and it is rather an interesting process.

Mr. J. L. Porter: I am sorry but I don't think I am qualified to explain the process offhand. Perhaps you could explain that better than I could. In any case, it is along the lines of the urea adduct situation where the complex takes a hold of one of the isomers in the case of xylene and the other is not absorbed into the system and then you can dissolve the complex away or change its form and it releases the absorbed isomers.

Dr. R. M. O'Brien: May I add that in a clathrate you are caging a neutral molecule, purely van der Waals forces are involved. You have to have a particular kind of solution or type of chemical to form the right kind of cage and you have to do it at the right temperatures and so on. While it has been known in the lab since 1948, I didn't think it had become a commercial process yet.

SECONDARY PETROCHEMICAL MANUFACTURE

J. C. Langford
Vice President, Canadian Chemical Company Ltd., Montreal, Quebec

> Mr. Langford was born in Blenheim, Ontario. He received his B.A.Sc. (Chemical Engineering) from the University of Toronto and his M.S. (Chemical Engineering) from the University of Michigan. He was employed in various technical capacities with Canadian Industries Limited, and Defence Industries Ltd. Later he was Plant Manager with Dominion Tar & Chemical Company, then Production Manager and Plant Manager with Canadian Chemical Company Limited, in Edmonton. He is presently Vice President of Canadian Chemical Company Limited, Montreal.

A discussion in depth of the manufacture of secondary products from primary petrochemicals is obviously far too broad to be dealt with in detail here. Even if the field were narrowed to Alberta the discussion would be lengthy. This area already is a major producer of a wide variety of secondary petrochemicals. A review of the current picture would list ammonia based materials in considerable variety, ethylene polymers, a variety of ketones, aldehydes, alcohols and esters, sulphur and many other products. As the market in Alberta and in Canada enlarges there will be constant growth of this list.

One facet of the secondary chemical picture which is of prime interest however, are those new processes which may be so adapted to economic and raw material supply conditions here that they may be used to advantage to fulfill not only growing local needs but also to compete in the exploding markets of the highly populated centres of the world.

Actual chemical manufacture of any type exists because of the right combination of delicately balanced economic factors. Product demand must exist with enough strength to support the volume and price necessary for economic operation. To further complicate this factor volume and price demonstrate an inverse relationship which must be predicted with some degree of accuracy. Raw materials must be available in adequate supply and with assurance of price stability to justify economic predictions over a capital payout period. The third factor of processing cost is of prime importance. In this area the dynamic nature of the industry with its technological improvements has been clearly demonstrated. The constant flow of new process developments must be critically examined and their impact on over-all economics of manufacture repeatedly evaluated if opportunity is to be translated into action. It would seem timely, therefore, to discuss two or three fields of technology which appear to be currently of interest and attempt to show their possible relationship to the Alberta and Canadian petrochemical scene.

One of the most interesting processes which is at present being applied in industry is the so-called Wacker process for the controlled oxidation of olefins. This process was developed jointly by Wacker Chemie and Hoechst in Germany and first tried industrially by Hoechst less than two years ago. In the process, which has been widely described in the literature,[1] ethylene is oxidised directly to acetaldehyde with air or oxygen in an aqueous solution of a cupric chloride and palladium chloride catalyst. This process is of particular interest since it should develop into a large scale method of producing acetaldehyde petrochemically. As you may be aware, the Canadian Chemical Company Limited process used in Edmonton also produces acetaldehyde in quantity by direct oxidation of petroleum fractions; however, it is co-produced with methanol, formaldehyde, and a number of other oxides, ketones and higher alcohols.

A substantial volume of present acetaldehyde manufacture is via acetylene. This route was first based on calcium carbide produced acetylene, although some plants now utilize petroleum-based acetylene as a raw material source. The Wacker process permits direct production of acetaldehyde without substantial by-product formation from a primary petrochemical produced in large volumes and with a stable price basis in most countries of the world.

An examination of the funadmental economics involved in the Wacker process is very interesting. Because it is a very direct process the economics are very much dependent on raw material ethylene cost, and while the end product acetaldehyde is widely used as a chemical intermediate, it is not of high unit value and thus cannot bear too high transportation charges to its markets. The process, however, would seem to be attractive to Alberta if the raw materials available in Alberta were low enough cost and, preferably, if the acetaldehyde could be further processed in Alberta to yield high enough value products that transportation charges to the Canadian and world markets would not be too great a proportion of the product price. These two criteria comprise the key to the future of most chemical industry in Alberta. Low cost raw materials, large volume, and high unit value products are essential to the economics of manufacture. These factors must compensate for the advantage of manufacture close to the high density markets in the East and in Europe, or to a location where relatively cheap water-borne transportation can be utilized. If raw materials are moved from this Province to these dense market areas at a landed cost only slightly above their price in Alberta, then no advantage can remain for manufacture here. Both criteria must be exploited to the limit by Alberta manufacturers; products must be upgraded to high value to minimize the effect of transport charges to market, and raw materials cost must be maintained at the lowest possible level compared to their cost in the more heavily industrialized areas of the East and Europe.

The two factors of low cost, high volume ethylene and integrated facilities to upgrade acetaldehyde would be necessary to generate active interest in the process in Alberta. Acetaldehyde represents a very valuable chemical building block, for which a wide variety of processing steps already exist. Its future uses to a great degree depend on its ability to meet the requirements of a chemical raw material. It must be volume produced and be capable of processing economically to meet or generate an end product demand. This is an example of a very old chemical for which new uses can be anticipated if it can be volume produced at a progressively lower cost.

Another facet of recent chemical technology which is of current active interest today is in the developments on the production of a variety of new high molecular weight alcohols. These materials find an increasing market in their use in synthetic detergents and as raw materials for plasticizer manufacture for the rapidly expanding high polymer industry. Two new processes for production of the higher alcohols are the Humble Oil & Refining Co. "Aldox" process and the Continental Oil Co's "Alfol" process.

The "Aldox" process basically is a variation of the old Oxo reaction with a new catalyst which promotes dimerization during aldehyde formation[2,3]. The process utilizes olefins to yield primary alcohols with 2n plus 2 carbon atoms where n is the number of carbons in the feed. The main advantage in the "Aldox" reaction over that of the traditional Oxo process is in its unusually high yields and its ability to use more readily available lower olefins as raw material. It again should be a process which would merit economic study for Alberta conditions. It uses as feed stock carbon monoxide, hydrogen and olefins, which should be economically manufactured here, and produces a relatively high unit cost product with good volume prospects in a diversified market. The original Oxo process has not gained acceptance in Canada, largely because of the scale required for economic operation; this new modification could provide the additional incentive to permit an operation here.

The Continental "Alfol" process is also of specific current interest[3,4]. This process involves an application of the Ziegler technique to produce straight chain alochols from ethylene. In actual practice it is not possible to produce a single chain length primary alcohol by itself, and a mixture of higher alcohols are formed. Some control can be exercised on both the average molecular weight produced and similarly on the spread of the chain lengths, but as yet it is not possible to produce a single chain length nor to completely eliminate the formation of some branched chain materials. In spite of these limitations the process is attractive as a direct route to higher alcohols.

While the major use for alcohols of this type has been in the manufacture of plasticizers for plastics use, there has been much speculation on the potential market for these types of alcohols in detergent manufacture. Straight chain alcohols derived from animal and vegetable oils have been used for some time for detergent manufacture, and the "Aldox" and "Alfol" processes are of interest in providing a petroleum-based source of similar materials. The present interest in sulfonated straight chain alcohol derived detergents springs from this factor and from their reported ability to be more easily biologically degraded in municipal effluent treatment than the alkyl benzene sulfonates. Public interest in this problem is increasing and legislation limiting detergent properties is already reported from Europe.

The economics of location of an American plant to produce straight chain alcohols has been discussed in the literature, and review of the conclusions would be particularly significant to a study of potential Canadian production[5]. The same two factors paramount in any study of this type of process are: (1) Market size and location, (2) Availability, location and cost of raw materials.

The first factor of market size and location is important for two reasons; it determines the potential size of an operation and the transportation cost to be borne by the product. The second factor of raw material availability and cost is important because of its economic effect on production costs. Location of industry invariably becomes a comparison of alternatives. In this case the advantages of location such that an economically large enough market is available without excessive transportation costs must be balanced with and against the advantage of location at the most assured source of the lowest cost raw material olefins. In Canada the raw material and the markets are a great distance apart. Our hydrocarbons are produced in Alberta and our large markets are at the best in eastern Canada; in fact, to achieve an adequate volume for economic sized competitive production they extend to Europe and other overseas continents. The economics of the new process developments described above typify the economic comparisons which must continually be made in studying secondary chemical manufacture. Until population in the west can consume the production from minimum economic-sized units, the relative advantages of cost and availability of hydrocarbon raw materials must be sufficient to outweigh the preference for a location near the markets of Canada and the world.

The conclusion should not be drawn that even the most attractive secondary chemical processes are doomed to failure if located in Alberta; rather this very brief review is intended to point up the factors which must be carefully examined in establishing secondary chemical processes here. There has been a wide-spread public feeling that Alberta chemical industry should automatically follow the pattern established in south Texas. It is true that similarities exist, but it is equally true that major differences are apparent. Geography and the present pattern of consuming markets are a present disadvantage to Alberta manufacture. The major advantage of raw material cost and availability must be maintained and, if possible, improved. In addition, the newest processing techniques must be exploited to yield the highest possible value products from these raw materials.

This combination of the most effective utilization of lowest possible cost raw materials to produce the highest possible value products should permit profitable sales in the large volume markets of the world and assure a sound diversified secondary chemical industry. The increasing local market, due to population increase and enlarged industrialization, will and can be readily satisfied by local manufacture, but the relatively much larger volume world chemical markets can only be satisfied by Alberta production with the proper combination of these factors.

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4. "Studies of the Reaction of Ethylene with Aluminum Trialkyls" - Ind. Eng. Chem., vol. 52, No. 8, Aug. 1960, p. 695.

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DISCUSSION

Mr. R. J. Abercrombie, Canadian Petroleum Association, Calgary, Alberta: I presume a large factor in deciding to build your plant in Edmonton was the result of low cost and stable supplies of raw materials, namely ethane and methane. Since you built your plant, which I note was in 1953, there have been some major developments in Canada: (1) the Trans-Canada Pipeline bringing reasonably priced product across Canada (2) a change in the freight rates. I just wondered, would the changes have made any significant effect on your decision to locate in Alberta. In other words, have the factors in favor of Alberta changed in the last eight or nine years?

Mr. J. C. Langford, Vice President, Canadian Chemical Co. Ltd., Montreal, Quebec: I would like to correct one minor misconception. We do not use methane and ethane as raw materials; we do make some hydrogen from methane but otherwise we oxidize propane and butane. As far as changes in raw materials and transport conditions which would affect our initial decision, I don't feel that there has been any drastic one. We have obviously tried to follow a pattern of improving freight rates transportation costs, since they represent such a large portion of our costs and I am sure any raw material suppliers here will agree that we already bargain quite hard for our raw material supplies. There certainly has been no policy change or drastic change in supply pattern of raw materials which would have caused us to change this decision. There was a gamble at the time we built here as to what the geographical center of the raw material supply area would be. I think we ended up with the right decision. We, happily, are located in roughly the geographical center of light hydrocarbon supply.

Mr. G. D. Garrett, Union Carbide Canada Ltd., Toronto, Ontario: I would like to ask Mr. Langford a question about the Ziegler process for making the straight chain alcohols that he was describing. You pointed out that to date they have not been able to wind up with any of the pure alcohol. I mean, if you were shooting at a 18 carbon atom alcohol you would get a distribution of alcohols on either side. Is there any information available on how close they have come? Supposing you were shooting at 18, what is the best they can do to date?

Mr. J. C. Langford: The most recently published data has shown an increasingly narrower range or higher peak of molecular weights. They are actually, as you probably know better than I, marketed in fractions which make it impossible to tell whether they obtain them by distillation or in actual selective production. But certainly the most recent published literature on alcohol processing indicates that they are achieving higher and higher peaks and therefore, narrower molecular weight ranges. I think it will be very difficult to estimate what total spread you would get at any particular average molecular weight.

PRODUCTION OF OLEFINS

L. Carter
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Mr. Carter is a graduate of Purdue University and has a Master's degree in Chemical Engineering from Cornell. During the past 15 years, he has been employed by the Stone & Webster group of companies in the U.S.A., Great Britain and Canada. Much of his work has been in process design especially as it is applied to oil refining, gas processing and petrochemicals. Mr. Carter has been in charge of Stone & Webster's Calgary office since 1959. He is a member of the Association of Professional Engineers of Alberta, Engineering Institute of Canada and Chemical Institute of Canada.

INTRODUCTION

Among the petrochemical intermediates there can hardly be conceived of any more fundamental group of compounds than the olefins. Structurally they have a similarity to the paraffins which occur so abundantly in natural gas and crude oil. In spite of this similarity, olefins rarely occur in nature. This situation is readily explained by the ease with which olefins react either with other materials or, by polymerization, with themselves.

Historically, the curiosity of the chemist set a more rapid pace than the evolution of the oil refinery and the olefins were well known before petrochemicals were given their name. One of the most elegant ways of producing ethylene in high yield and with a minimum of apparatus is by the catalytic dehydration of alcohol. However, from the viewpoint of modern economics and the special regard which some of us hold for alcohol this might border either on folly or on sacrilege. Today, the reverse reaction for the synthesis of alcohol from ethylene and water is widely practised except in connection with the production of beverages. This important field is still reserved for fermentation.

The relationship between ethylene and the other commercially important olefins: propylene, the butylenes and, if we admit pairs of double bonds, butadiene should be clarified before we go any further. Ethylene is the olefin with the greatest volume of production and generally the olefin that is produced, for itself alone, as a primary product. With only a limited number of exceptions, all of the rest have their origin as by-products either of ethylene production or of petroleum cracking for motor fuel production. Although the rest of this paper will tend to keep ethylene in the center of the stage, frequent reference will be made to other members of the family.

It is the purpose of this paper to look at the subject of the production and purification of olefins rather critically and to examine some of the specific problems that now exist or which would arise concurrent with expanding ethylene production in the province of Alberta. While the major emphasis will be placed on the production and purification of olefins, market requirements, storage and transportation will also be discussed. The various alternative solutions to the several problems will be considered and some conclusions will be stated as to the most advantageous procedures.

DISCUSSION OF PROBLEMS AND ALTERNATIVE SOLUTIONS

A. Markets for Olefins

The most serious difficulty which must be faced in Alberta today when planning olefin production is that of finding truly adequate markets. There are other portions of the present program in which I am sure the problem of markets will be dealt with in great detail. We have a population problem. We have a transportation problem. Even though the complexities of the market place may lie in areas where we are the least prepared to offer sure solutions, we are bound in all logic to list Markets as problem number one. The ethylene currently produced by CIL in Edmonton is dedicated to polyethylene production. Dow is converting ethylene to glycol in Fort Saskatchewan. What will be the new markets for ethylene and the other olefins?

To give some indication of the nature of the existing and probable markets for ethylene, it is interesting to consider the relative importance of its various derivatives. Table 1 shows the percentage distribution both in Canada and the U.S.A. of ethylene between the listed end-uses. In the case of the Canada figures the word "other" includes the named end-uses for which no quantity is shown. A prediction was available of 1965 figures for the U.S.A. and it will be observed to contain no radical change in pattern. It is interesting to note that in both countries 75% of the ethylene production is used and presumably will continue to be used in making three products; ethylene oxide, ethyl alcohol and polyethylene. Agricultural interests in Canada will perhaps have a restraining influence on our making synthetic alcohol.

Table 1. Consumption of Ethylene in Making Specific Products
(Percent of Ethylene Produced)

	Canada 1960	USA 1960	USA 1965
Ethylene Oxide and Glycol	34	30	30
Ethyl Alcohol	Note "A"	21	18
Polyethylene	41	25	27
Styrene	18	9	9
Ethyl Chloride	Note "A"	7	7
Ethylene Di Chloride Ethylene Di Bromide	Note "A"	6	5
Other	7	2	4
	100	100	100
Annual Production (Million pounds)	220	5,000	6,500
Plant Capacity	410		

Note "A" included in the heading "Other"

Source: Davenport, C.H. - Petroleum Refiner, Page 128, March 1960.
Law, C. - Petro Process Eng. Page 31, March 1961.

Exploring the problem of markets for olefins that might be produced in Alberta is complicated by the fact that the olefins are chemical intermediates and not finished products. For example, this intermediate character severly restricts the amount of statistical information which can be obtained from the Dominion Bureau of Statistics. If the olefins were finished products and particularly if they were finished products used by everyone, for example - soap, the market could be surveyed directly and interpreted statistically. As in the case of any chemical intermediate three possibilities present themselves with regard to marketing. The producer may actually manufacture a finished product from his own olefin production as in the case of CIL polyethylene. This is termed a "captive" market. The producer may have a contract to sell all of his olefins to a single consumer. This makes him a "custom" producer. Finally, the producer may offer his olefins to a whole group of nearby consumers whose membership and whose interests are subject to change. This constitutes the definition of a "merchant" producer.

To assess a "captive" market in which you are contemplating production is essentially to assess the intentions of one's own company. These intentions can be influenced by the nature of the proposed finished product, its local or regional market potential and the freight rates and price structures of remote markets either inside Canada or abroad. Without elaborating upon them, two factors well known to us all are the relatively low population of western Canada and the relatively high freight rates to other centers.

To assess a "custom" market is usually only a matter of negotiating with the intending buyer of the olefins. He in turn takes the burden of deciding how he will sell his finished product. Thus if you are about to sell ethylene to an ethylene glycol manufacturer, he would be the one to assess the glycol market.

The most difficult task of the three is posed by having to consider going into the "merchant" ethylene (or other olefin) business. It is common knowledge that there are in the Edmonton area two or three important ethylene users. What are the chances of some fourth party successfully undertaking to serve, let us say, all of them with incremental amounts of ethylene? The answer might depend partly on negotiations with the potential consumers and partly on boldness. Safeway doesn't get contracts from the local housewives before it opens up a store and there are indications (Ref. 9) that Imperial Oil took something like that attitude in 1958 when it built its Sarnia ethylene plant.

Another way in which markets influence the economics of olefin production is by setting plant size. If experience in other parts of the world and engineering considerations point to a certain optimum plant size and if markets and potential markets can justify only a much smaller plant size, it is obvious that there will be an adverse effect on the economics of the plant located in the restricted market area.

Here then, are some of the problems involved with marketing. We shall come to a consideration of selection between marketing alternatives after looking at the other variables, in feed stocks, in techniques and in storage and transportation.

B. Selection of Feed Stocks

The problems which arise in the selection of feed stocks are considerably more amenable to an engineering-type solution than those of marketing. We in Alberta are blessed with a multiplicity of raw-materials of petroleum and natural gas origin. Essentially all of them can, if the economics are right, be employed in making olefins. Nevertheless, when the time comes to pick and choose between feed stocks, the intending olefin manufacturer is faced with a fairly complex economic problem. It is immediately apparent that he needs the prices of each of the potential feed stocks and an appreciation of the validity of these prices for the actual quantities required. The probable price variations that could occur over a period of years also demand attention.

Equally as important as the price of the feed stocks is a knowledge of the yield pattern to be expected from each. When starting with a simple feed like ethane for ethylene production, the identification and the assignment of values to by-products is not very important. However, as the molecular weight of the charge stock goes up, the by-products become more numerous and occur in larger quantities. This is illustrated by Table 2. An important factor deliberately omitted at this point in our discussion is the effect of cracking severity on yield patterns. For the moment, we shall deal with only an illustrative set of yield patterns at a typical level of severity for each feed.

Table 2. Typical Conversion Data Using Various Feed Stocks

The figures given are for a single pass through the cracking coil. Unconverted ethane and propane are usually recycled.

	Ethane	Propane	Butane	Natural Gasoline		Naphtha 52.2 API		Gas Oil 37 API	
	Mol.%	Mol.%	Mol.%	Wt.%	Mol.%	Wt.%	Mol.%	Wt.%	Mol.%
	A	A	A		B		B		B
Ethylene	33.1	25.7	23.6		27.6		26.7		26.9
Propylene	0.3	8.7	12.5		12.5		15.1		14.0
Total C_4 & Lighter	99.7	98.1	96.7	73.5		57.5		56.5	
C_5+	0.3	1.9	3.3						
C_5 to 375° EP				21.0		35.2		21.3	
Fuel Oil & Carbon				5.5		7.3		22.2	
	100.0	100.0	100.0	100.0		100.0		100.0	
Conversion per pass %	58.8	83.0	85.9						
Ultimate Yield Wt.%	81.0	44.0							

A. Mol. percent referred to entire product.

B. Mol. percent referred to C_4 and lighter product only.

Source: H.C.Schutt & S.B.Zdonik - Making Ethylene. A series of six articles in the Oil and Gas Journal, 1956.

1. Ethane, separated from natural gas is the most logical raw material for making ethylene from the viewpoint of the chemistry involved. It is the feed stock of the existing CIL ethylene plant here in Edmonton. The separation of ethane from natural gas can be justified in cases where there is a fairly rich ethane content, perhaps on the order of 10 volume percent. It can also be justified if the gas stream is at the same time a source of Liquefied Petroleum Gas which upon separation can be marketed to help cover the cost of a combined ethane - L.P.G. separation plant. In either case, the gas stream would normally have to be available close to the proposed plant site, the cost of pipelining it into the area having already been allocated to its fuel value.

Historically, the separation of ethane and L.P.G. from pipeline gas often has been accomplished many hundreds of miles from the producing gas fields in regions of high industrial activity with easy access to markets. For a petrochemicals industry located in close proximity to gas fields, as in Alberta, the separation of ethane may be more economical if it is done in the basic field gas processing plant, which exists primarily to produce pipeline specification gas, instead of in a separate facility. This would require some additional equipment but, if the problem is recognized when the plant is being designed, a single plant to make both ethane and specification pipeline gas could be more economical than two separate plants. It is noted that the Oil and Gas Conservation Board has had before it recently proposals to separate ethane and L.P.G. from gas streams and involving the ideas just mentioned (Ref. 10).

As shown in the first column of Table 2, a conversion per pass of 58.8% of the ethane in the feed is typical and the ultimate yield of ethylene as weight percent of the ethane in the feed is 81%. Considering the differences in molecular weights, a perfect conversion would be about 93% by weight of the feed ethane.

2. Refinery Cracked Gas is an excellent starting material for ethylene manufacture where oil refineries are big enough and where they employ extensive cracking facilities in the manufacture of gasoline. A typical analysis of such a gas is shown in Table 3. It has been estimated by Schutt and Zdonik (Ref. 3) that a refinery throughput of 75,000 barrels per day is about the minimum economic size to have an associated ethylene plant based on refinery cracked gas alone. Today the three Edmonton refineries together do not have this capacity so their cracked gas, if they could be persuaded to sell it, would only partially fill the stated requirements. As will be noted in Table 3, the refinery gas is both a source of ethylene as such and a source of ethane for further cracking. Refinery gas often contains hydrogen sulfide, carbonyl sulfide and carbon dioxide which must be removed before fractionation. If available at high pressure and with a reasonable ethylene content, the ethylene and ethane may be fractionated out, using procedures to be discussed later, and an ethane stream sent to pyrolysis. If free of acidic components and at a lower pressure and lower ethylene content, the entire mixture is sometimes cracked without prefractionation.

Table 3. Typical Analysis of Refinery Cracked Gas
Exclusive of Acidic & Inert Gases

	Mol Percent
Hydrogen	12.5
Methane	44.8
Ethylene	9.5
Ethane	22.8
Propylene	1.8
Propane	6.2
C_4 and heavier	2.4
	100.0

Source: H.C. Schutt & S.B. Zdonik - Making Ethylene.
A series of six articles in the Oil and Gas Journal, 1956.

3. Liquefied Petroleum Gas is a useful olefin production feed stock. It should be noted that, once the C_3 - C_4 hydrocarbons are employed for this purpose, conversion processes result not simply in ethylene production but also in an opportunity to recover propylene and other members of the olefin series.

Liquefied Petroleum Gas or L.P.G. is a standard article of trade. It is widely used as a fuel in regions not on gas mains. With the inception of large scale gas export in our own region, increasing production makes it likely that the price of by-product propane and butanes will remain at a moderate level. Because of its higher volatility in cold weather, propane finds a more ready market here as bottled gas than do the butanes. This is one reason why liquid hydrocarbons of the C_4 group, i.e. normal and iso butane, tend to be cheaper than propane. A 1961 market survey (Ref. 10) suggests a price of 4.5 cents per imperial gallon for propane and 3.5 cents per imperial gallon for butane. However, the existance of the two C_4 isomers poses a significant problem in cracking of butanes for ethylene. Iso butane which can amount to 30% of the C_4 hydrocarbon mixture is much less satisfactory than normal butane as an ethylene raw material. Figures 5 and 6 which will be discussed later under "Product Distribution" illustrate the variations in yield which are encountered.

Referring back to Table 2 we find in the second and third columns some yield information on the cracking of propane and normal butane. Notice how with increasing feed molecular weight the ethylene yield is declining and the propylene yield is increasing.

4. Natural gas condensate is a commodity which is also becoming more and more plentiful here in Alberta as the export of natural gas to California and the Mid-Western United States expands. For this reason it deserves consideration as an olefin production

feed stock. The term natural gasoline is broadly synonymous with natural gas condensate. This material contains hydrocarbons in the C_5, C_6 and C_7 range. In Table 2 data are also given for ethylene yields from this feed stock. It will be observed that they are fairly attractive. Although the number of possible compounds present in a condensate is greater than in any lower boiling mixture, complete analyses of such potential feed stocks are quite possible and could result in selecting the most attractive stream available say from 2 or 3 different gas fields. By analogy with the iso butane - normal butane situation, the most attractive stream would contain a maximum of straight chain hydrocarbons.

5. Naphtha is a term which is used to describe a narrow boiling range cut in the general area of gasolines. One well known use for naphtha is as painters' solvent. In regions such as Europe, where some gasoline range material is in oversupply or at least more easily obtained than are the lighter hydrocarbons, naphtha has a place as an olefin production feed stock. In fact, the cracking operation whereby olefins are made from naphtha is often regulated so as to produce not only olefins for petrochemical use but also an up-graded cracked gasoline to be sold as motor fuel. If marketing conditions are favorable, this is an example of where low severity cracking can be profitable. On the other hand, high severity naphtha cracking has a place in the olefin production business in Japan. The column headed Naphtha in Table 2 is a low severity example. Again, a substantial propylene yield is obtained.

6. Heavier Materials including distillates in the gas oil or diesel fuel range are also employed as feed stocks in olefin production. This has been particularly true of petrochemical enterprises in which crude oil is purchased, not for general refinery purposes but to make as large an output of petrochemicals as possible, independent of the refining industry. In such instances every practical fraction of the crude is employed as feed. Yields of ethylene tend to be lower than for other feed stocks and the C_4 and heavier cracked materials are produced in larger quantities. An adequate market for by-products becomes an economic necessity and, in a certain sense, the petrochemical operator finds that he is an oil refiner. The most significant difference to be noted in comparing the naphtha and gas oil columns in Table 2 is the change in distribution between the C_5 to 375°F. EP distillate and the item Fuel Oil & Carbon.

Residual oils, which are too high boiling to be distilled in the processing of crude oil, are less desirable as olefin feed stocks by logical extension of the same reasoning as stated for the heavy distillates. In addition residual oils cannot be handled in coil-type furnaces because they lay down far too much carbon.

7. Comparative Costs of feed stocks for olefin production is of course a subject of great interest to everyone in the petrochemical industry. It should not be expected that cost figures of great authority and wide application will be automatically available for long term and large scale purchases of feed stocks because they are more likely to be negotiated purchases. Table 4 bears the title "Comparative Costs of Ethylene Starting with Various Feed Stocks". It supplies exactly that information for the year 1956 and for the U.S. Gulf Coast only with respect to ethane and propane feeds. As shown in

Table 4 the appraisal of ethylene costs when using other higher molecular weight feed stocks becomes complicated by the necessity of assigning appropriate by-product values. In general, to do this effectively will involve not only research but negotiation with potential buyers.

Table 4. Comparative Costs of Ethylene Starting with Various Feed Stocks (Commercial scale of operation, U.S. Gulf Coast, 1956)

Value of Feed Stock		Resultant Ethylene Cost
1¢/pound	Ethane	3¢/pound
3.5¢/U.S.Gal.	Propane	3.8¢/pound
	Butanes Condensate Naphtha Heavier Materials	Depends very greatly on what realization is available for the by-products

Source: H.C. Schutt & S.B. Zdonik - Making Ethylene. A series of six articles in the Oil and Gas Journal, 1956.

C. Techniques for Conversion and Purification

1. The Chemistry and Chemical Engineering of Pyrolysis involves such a volume of theoretical material that this subject can be outlined only briefly in this paper. About it have been written many books and papers, some of which are listed in the bibliography of this paper. Our purpose in dealing with it here is to provide some background for comparing the various pyrolysis techniques.

a. History

Pyrolysis in the oil refining industry was discovered accidentally in the overheating of batch crude oil stills. It was observed that in this operation, termed cracking, low boiling hydrocarbons and hydrogen were produced. The first practical use to which this knowledge was put was to operate existing plants temporarily and eventually to design special plants with the aim of increasing the yield of gasoline per barrel of crude by thermal conversion of higher boiling components.

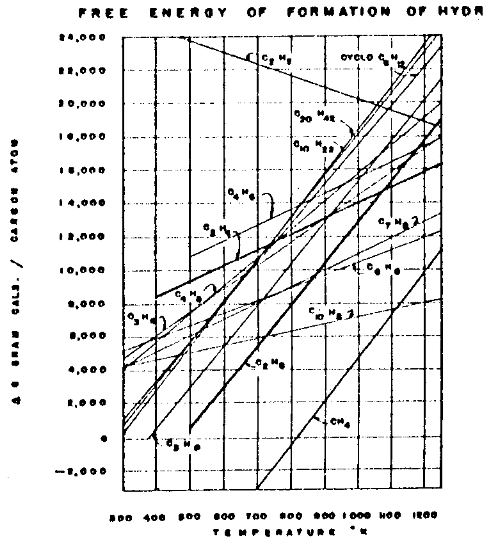
Only at a later date was attention directed toward the utilization of the resultant and concurrent production of gaseous hydrocarbons. Aside from their fuel value, it was noted that olefins, particularly ethylene and propylene, were present in such gas and could be separated and put to some chemical use. With this recognition began the olefin petrochemical industry.

In the late 1930's pyrolysis in the oil refinery for gasoline production graduated from purely thermal processing to more complex and selective catalytic processing. Although experimental work has been done on catalytic pyrolysis where olefin production is the chief objective, little has come of it commercially. One example of catalytic pyrolysis on which an important petrochemical operations was based is the Catarole process used in Manchester, England. Generally, petrochemical olefin production continues to be a stronghold of purely thermal processing.

b. Selectivity of Reactions - Free Energy

In any pyrolysis operation there is a multiplicity of chemical reactions possible. The two simplest pyrolysis reactions of saturated paraffins are dehydrogenation which results in producing hydrogen and an olefin and chain rupture which results in producing a new shorter chain paraffin and an olefin. More complex reactions involve the production of acetylene, naphthenes and aromatics as well as polymers, tar and coke.

Considering for the moment only the relative thermodynamic stability of the various hydrocarbons, Figure 1 shows for a number of hydrocarbons a plot of free energy of formation per carbon atom versus temperature. In this diagram, at any particular temperature, reactions would tend to proceed from a higher to a lower curve. For example, above 1066°K or 1459°F., ethylene is thermodynamically more stable than ethane. In considering the implications of Figure 1, it must be borne in mind that chemical thermodynamics is only one aspect of chemistry. It suggests what can or cannot happen but doesn't tell the whole story about what will happen. In the following paragraphs we shall touch upon a number of other considerations which also have their effect on the whole story about what will happen.



SOURCE: GOLDSTEIN, THE PETROLEUM CHEMICALS INDUSTRY
2ND. EDITION PG.93 LONDON, E.&F.N. SPON 1958.

FIGURE 1. Free energy of formation of hydrocarbons

Table 5 shows details of the free energy relationships which prevail for the higher paraffins (i.e. C_5 and heavier) in connection with the two reactions of dehydrogenation and chain rupture. Since for any temperature level, a smaller or more negative free energy of reaction occurs on chain rupture, it will be deduced that, thermodynamically, the chain rupture reaction will be more likely to occur than the dehydrogenation reaction. Fortunately, this generalization is not always controlling. In the case of ethane cracking large yields of ethylene by dehydrogenation are commonplace. However, this theoretical consideration does suggest that making pentenes by direct pyrolysis of pentanes might be a rather futile exercise.

Table 5. Free Energy Relationships in Dehydrogenation & Chain Rupture
(Units Gram Calories per Gram Mol)

Free Energies of Formation at 700 - 1,000°K

Higher paraffins	— 12,606	— 5,963N + 25.3NT	
Higher olefins	19,058	— 5,963N + 25.3NT	— 33.6T

Free Energy of Dehydrogenation Reaction

$$C_NH_{2N+2} \qquad C_NH_{2N} + H_2$$

Free Energy Product — Free Energy Feed

$$\begin{array}{rrlr}
 & 19{,}058 & - 5{,}963N + 25.3NT & - 33.6T \\
 & -(-12{,}606 & - 5{,}963N + 25.3NT &) \\
\hline
\Delta G = & 31{,}664 & & - 33.6T
\end{array}$$

Free Energy of Chain Rupture Reaction

$$C_{M+N}H_{2(M+N)+2} \qquad C_MH_{2M} + C_NH_{2N+2}$$

Free Energy Product — Free Energy Feed

$$\begin{array}{rrlr}
 & 19{,}058 & - 5{,}963M + 25.3MT & - 33.6T \\
 & - 12{,}606 & - 5{,}963N + 25.3NT & \\
 & -\big(-12{,}606 & - 5{,}963M + 25.3MT & \\
 & & - 5{,}963N + 25.3NT & \big) \\
\hline
\Delta G = & 19{,}058 & & - 33.6T
\end{array}$$

Source: Goldstein, The Petroleum Chemicals Industry,
Page 94, Second Edition, London, E. & F.N. Spon. 1958.

c. Reaction Velocity and Percentage Conversion

In view of the fact that, for the simpler low molecular weight hydrocarbons, almost all of the pyrolysis reactions are decompositions involving first order relationships, such reactions have reaction velocity constants K_c which are related to reaction time θ and fraction converted X according to the formula:

$$K_c\theta = 2.303 \log_{10} \frac{1}{1 - X}$$

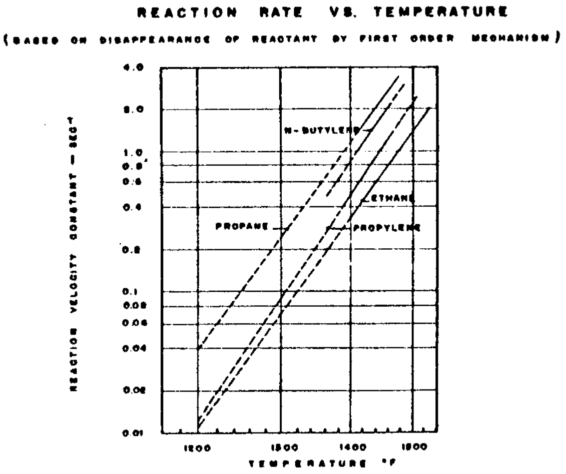
where:

K_c = reaction velocity constant

θ = reaction time seconds

X = fraction converted.

Thus, if the percentage conversion of one component in a mixed feed is known at a given temperature, it is possible to read off a value of K_c from charts such as Figure 2. With one such value, a corresponding value of θ, or an effective reaction time, can be calculated. This value of θ combined with K_c for a second component will lead to a solution for the percentage conversion of that component. In general, the higher the molecular weight of the feed component the more rapidly it reacts. For this reason caution is required in cracking mixtures of hydrocarbons having varying molecular weights in order to prevent overcracking to tar and coke in the case of the higher boiling component while undercracking the lower boiling. Instead, it is preferable to employ narrow boiling range cuts in separate furnaces run at optimum conditions for each specific feed.

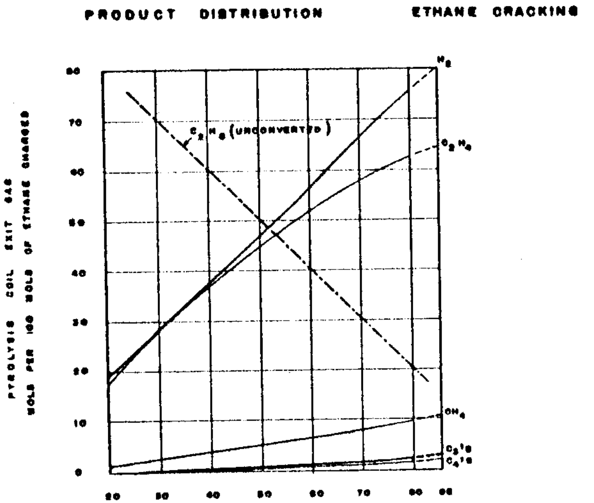


SOURCE : H.C. SCHUTT — PRODUCTION OF ETHYLENE FROM ETHANE, PROPANE CHEMICAL ENGINEERING PROGRESS PG. 115, MARCH, 1947.

FIGURE 2. Reaction rate vs. temperature.

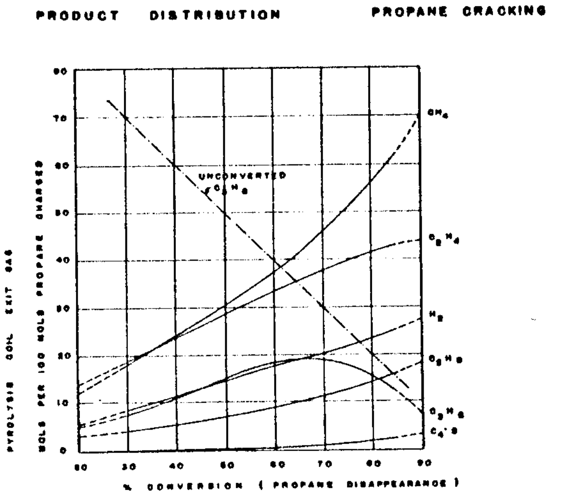
d. Product Distribution

It has been found by experience that a group of product distribution charts can be devised which show the empirical results of cracking such typical hydrocarbons as ethane, propane, butane and isobutane at various levels of conversion. Figures 3, 4, 5 and 6 present this information. It is to be noted on each figure that, for any specified level of conversion, the corresponding quantities of hydrogen, ethylene, methane and other products can be read off. In the case of a mixed feed it is possible to get a good practical answer to the over-all composition of the pyrolysis effluent by developing the percentage conversion for each feed component as discussed above under reaction velocity, reading off its product distribution at that conversion level and then compositing the products in the proportion that existed between feed components at the inlet. Obviously this procedure is both arbitrary and non-rigorous. Nevertheless, it turns out to be accurate enough to be quite useful.



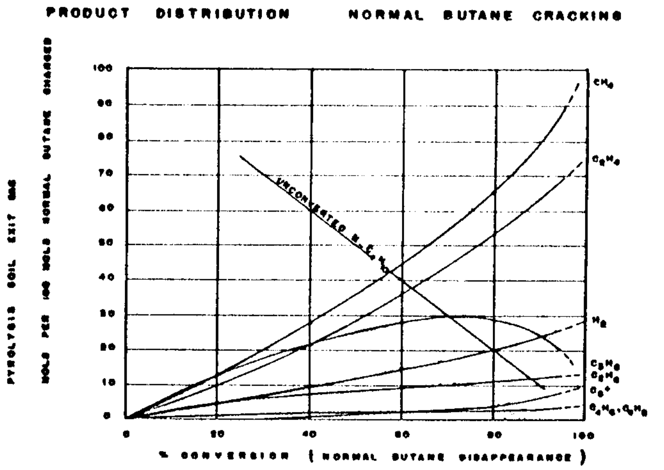
SOURCE : H.C. SCHUTT – PRODUCTION OF ETHYLENE FROM ETHANE, PROPANE CHEMICAL ENGINEERING PROGRESS PG. 107, MARCH, 1947.

FIGURE 3



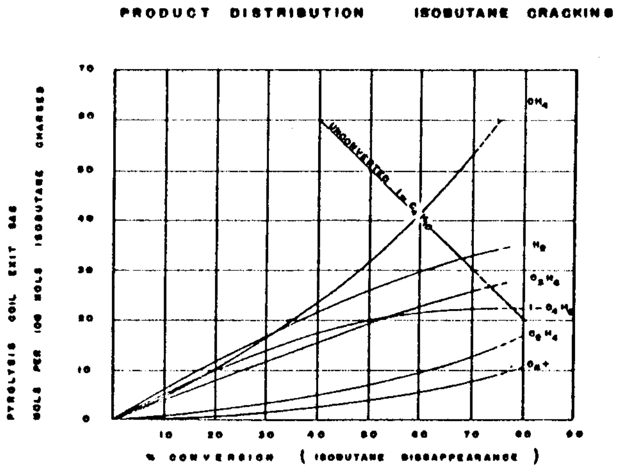
SOURCE : H. C. SCHUTT — PRODUCTION OF ETHYLENE FROM ETHANE, PROPANE CHEMICAL ENGINEERING PROGRESS, PG. 106, MARCH 1947.

FIGURE 4



SOURCE : FAIR, PERKINS & RASE — COMPARING OLEFIN UNIT FEEDSTOCKS
PETROLEUM REFINER PAGE 193, NOVEMBER, 1958.

FIGURE 5



SOURCE : FAIR PERKINS & RASE — COMPARING OLEFIN UNIT FEEDSTOCKS
PETROLEUM REFINER PG. 193, NOVEMBER, 1958.

FIGURE 6

The percentage conversion is closely related to the concept of cracking severity. As already mentioned in connection with the pyrolysis of mixtures, undue severity results in excessive production of tars and coke. Actually, in studying possible product distribution patterns it is often convenient to consider a high severity and a low severity case and to decide between them on the basis of which has the more advantageous pattern of by-products. The upper limit of cracking severity is discussed in the next section of this paper on Equilibrium Considerations.

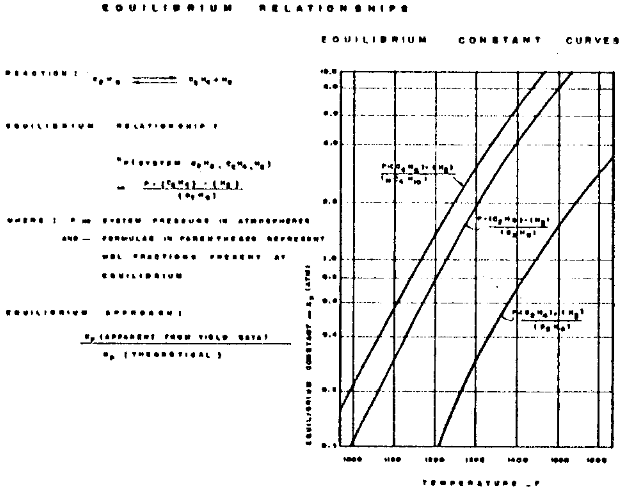
Another significant topic in product distribution studies is that of carbon and hydrogen balances. When using various correlations and empirical information from actual plants, it is possible to become unduly optimistic about olefin yields. When an effort is made to press ethylene yields upward, careful check calculations should be made to see that inputs equal outputs on both carbon and hydrogen. A characteristic problem is the hydrogen deficiency which can be observed by considering a series of cases in which the molecular weight of the charge stock is increased and its aromatic constituents are increased while the cracking reaction is being pushed to the point of maximum ethylene yield. In that situation an element by element material balance can help prevent erroneous conclusions.

e. Equilibrium Considerations

At a given temperature each particular chemical reaction having the simple form illustrated by ethane dehydrogenation: $C_2H_6 \rightleftharpoons C_2H_4 + H_2$ has an equilibrium constant:

$$K_p \text{ (system } C_2H_6,\ C_2H_4,\ H_2) = \frac{P(C_2H_4)\quad P(H_2)}{P(C_2H_6)}$$

The values of three such dehydrogenation equilibrium constants are plotted in Figure 7.



SOURCE: H.C. SCHUTT & S.B. ZDONIK — MAKING ETHYLENE, A SERIES OF SIX ARTICLES IN THE OIL & GAS JOURNAL 1956

FIGURE 7. Equilibrium relationships

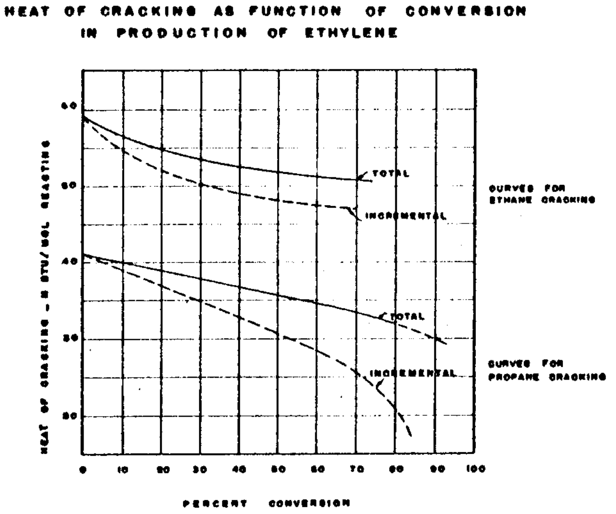
An interesting and valuable empirical criterion has arisen out of the ethane dehydrogenation equilibrium relationship. Arbitrarily disregarding what the nature of the charge stock may be, when a yield pattern or over-all product distribution has been developed, the proposed ethane, ethylene and hydrogen concentrations can still be combined in accordance with the formula for the above specific equilibrium system and an "apparent equilibrium constant" calculated. A more precise term would be "pro-forma equilibrium constant" since proposing a yield pattern really doesn't constitute proposing any equilibrium at all.

If this "apparent equilibrium constant" is then divided by the theoretical equilibrium constant (at the proposed operating temperature) for ethane dehydrogenation a ratio which is termed "Equilibrium Approach" is obtained.

The "Equilibrium Approach" is both a criterion of plausability of the yield data and an indication of the practical upper limit of cracking severity. For example when cracking normal butane at an approach of 0.6 or 60% no detrimental side-reactions need be considered but as 100% is approached, the side reactions become very harmful to ethylene and propylene yields. If a proposed yield structure were such as to suggest over 100% equilibrium approach, it would be suspect for impracticability because of unreasonably high severity. The absolute validity of this criterion decreases with increasing feed molecular weight but, in any event, it is generally a check worth making.

f. Heat of Reaction

Another important consideration in pyrolys s for olefin production is the heat absorbed by the chemical reaction involved. In general, all pyrolysis reactions absorb heat or are endothermic except at very high conversions of high molecular weight feeds. Figure 8 illustrates heat of reaction data for cracking ethane and propane. Empirical data are of course available based on actual operation of plants cracking any number of different feed stocks of varying complexity and at various levels of severity. The design of a cracking furnace is dependent upon a knowledge of the heat of reaction requirements.



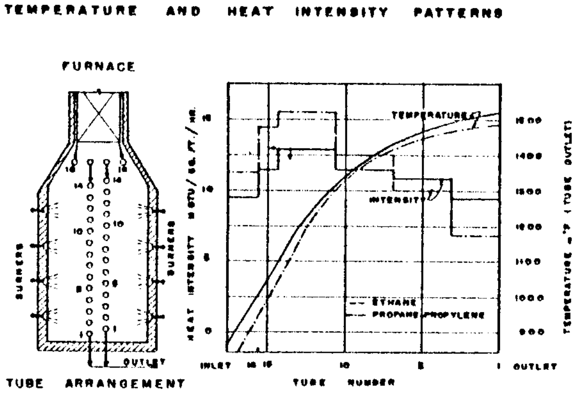
SOURCE: H.C. SCHUTT & S.B. ZDONIK — MAKING ETHYLENE, A SERIES OF SIX ARTICLES IN THE OIL & GAS JOURNAL 1956.

FIGURE 8. Heat of cracking as function of conversion in production of ethylene

2. Types of Pyrolysis Plant which are commonly used in producing olefins by thermal means, fall in the four distinct categories of tubular fired heaters, steam heat carrier, stationary refractory and moving bed refractory. Each of these will be described in turn.

a. Tubular Fired Heater

This is a fairly conventional device akin to the oil refinery furnace customarily employed in distillation and cracking units. The temperatures employed in olefin production are higher than employed in typical refinery cracking units. An order of magnitude idea would be conveyed by considering 1000°F. for the refinery vs. 1400°F. for the olefin unit. In the case of an olefin plant the temperature gradient, residence time and steam diluent rate become matters of critical importance. Adverse variations from the desired values, even if they might be considered trivial in ordinary oil refinery units, can result in low yields and rapid lay-down of coke in the tubes. One arrangement that has been found very useful in obtaining good temperature control is to use a multiplicity of burners arranged so that adjustment in their firing rate can establish precise temperature gradients.



SOURCE: H.C. SCHUTT & S.B. ZDONIK — MAKING ETHYLENE, A SERIES OF SIX ARTICLES IN THE OIL & GAS JOURNAL 1956.
FURNACE IS SELAS TYPE

FIGURE 9. Temperature and heat intensity patterns

Figure 9 shows diagrammatically the temperature and heat density patterns obtained with a specially designed furnace which has these characteristics. The solid curves represent ethane cracking while the dotted curves are for C_3 cracking. It will be noted that, while the two temperature curves are very similar, the heat intensity is much more uniform for ethane cracking. Table 6 lists typical steam diluent figures. With severe cracking more steam is required as the feed molecular weight increases. In the case of naphtha both mild and severe figures are given with the latter being the higher. The usual residence time in the cracking coil of an ethylene production pyrolysis furnace is in the range of 0.6 to 1.3 seconds. This residence time is an inherent situation controlled by the physical requirements of making a coil that is structurally feasible and has reasonable heat transfer rates. Although the tubular fired heater is the most widely used type of pyrolysis plant, one of the reasons for trying other designs is that shorter residence and higher temperature combinations hold some attraction.

Table 6. Typical Steam Diluent Figures

Charge Stock	Mols Steam per mol of Hydrocarbon Feed	
	Mild	Severe
Ethane	--	.3
Propane	--	.35
n Butane	--	.35
Pentane +	--	2.75
Naphtha	3.5	8.2
Gas Oil	4.0	--

Source: H.C. Schutt & S.B. Zdonik - Making Ethylene.
A series of six articles in the Oil and Gas Journal, 1956.

b. Steam Heat Carrier

This type of plant is one answer to the problem of attaining higher temperatures for shorter times. In such a plant pre-heated hydrocarbon vapors and steam at over 1700°F. are brought together in a reaction zone. The heat absorbed when causing cracking reaction to occur in a non-fired zone results in a fairly abrupt drop-off in temperature, thereby eliminating some adverse side reactions. The quantity of steam required for heat balance purposes is greatly in excess of that ordinarily employed as coil diluent to reduce the hydrocarbon partial pressure. While this is an advantage in preventing coke formation it also results in much heavier effluent cooling loads. The most attractive applications of the steam heat carrier have been in sensitive conversion processes such as the dehydrogenations involved in making butadiene and styrene with which many undesirable side reactions could occur.

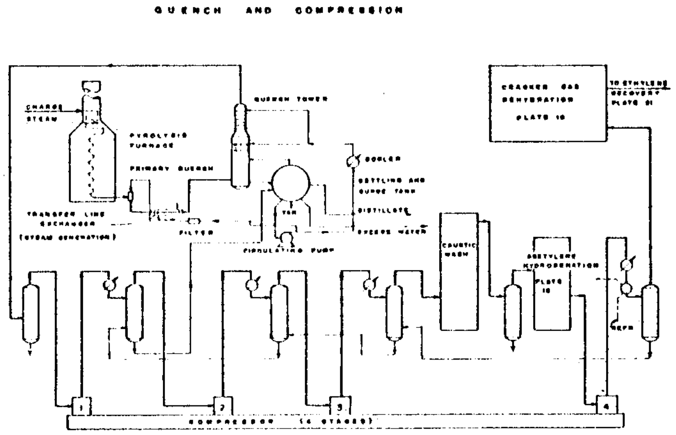
c. Stationary Refractory

These plants are characterised by the same equipment used in the production of the so-called "manufactured gas" which was distributed in cities before natural gas was available. It involves a regenerative gas-phase cracking operation using two furnaces filled with brick checkerwork. On the heating end of the cycle the refractory mass is brought up to temperature by combustion of fuel. When the checkerwork is up to operating temperature the gaseous feed stock or even a sprayed liquid is passed through it and cracked by the resultant heat pick up. When using this system coke laydown on the refractory is generally of no consequence, since it is burned off again on the next cycle. Objections to this type plant are that it is cumbersome, expensive and has high maintenance costs. It also produces a varying analysis of products at different points in the cycle.

d. Moving Bed Refractory

This type plant has also been suggested and developed to do the same job as the stationary refractory checkerwork. Oil refinery equipment developed for circulating solid catalyst through reactor and regenerator beds has served as a prototype. If the refractory solid is non-catalytic and can be circulated with a high enough temperature pattern, it will do a satisfactory pyrolysis job. Such a unit should be more compact and less expensive to construct than the older stationary bed type. Nevertheless, there is no great interest displayed by the industry in this type equipment.

3. Quench and Compression steps follow the pyrolysis reaction. Regardless of the type of pyrolysis plant, the effluent gas will require the same general treatment to halt effectively the chemical reactions that were going on at an elevated temperature, some of which tend to convert olefins into polymers and tars, and to facilitate the fractionation that is to follow. A diagram of quench and compression facilities is shown in Figure 10.


QUENCH AND COMPRESSION

SOURCE. H C SCHUTT & S B ZDONIK — MAKING ETHYLENE, A SERIES OF SIX ARTICLES IN THE OIL & GAS JOURNAL 1956

FIGURE 10. Quench and compression

As the gaseous products leave the cracking furnace, hot water can be injected which is rapidly vaporized. The resultant gas temperature after mixing may be about 700°F. and the whole mixture can be sent to the quench tower. This is the simplest procedure and the cheapest from a plant investment standpoint. However, it may be better economics to endeavor to recover some of the high temperature level heat content of the cracked gas by steam generation. For this purpose transfer line exchangers have been developed. An important criterion in their design is the hydrocarbon dew point of the coil effluent mixture. Since it is detrimental for any hydrocarbon to condense out in the heat exchanger (polymer, gum and coke deposits) the operating temperature on the heat absorption side is easily adapted to direct steam generation only when the conversion products (as in ethane cracking) are practically free of tars and high boilers. Direct steam generators have been designed for applications where high-boilers are present by careful attention to cracked hydrocarbon effluent velocities and residence times. In older installations, a high temperature, low vapor pressure heat transfer medium like Dowtherm was employed and circulated to an adjoining steam generator.

The next piece of equipment which the cracked gas mixture enters is the quench tower. In it the high boiling hydrocarbons and the greater part of the steam in the mixture are condensed, the lighter hydrocarbons continuing onward in the vapor phase while the water and condensed oil are sent to a separator surge tank. Where water quench is employed, it is advantageous to recirculate the water from the separator surge tank for that purpose so as to avoid losses of gases and valuable conversion products as well as the hazard of their release in effluent mains or cooling towers.

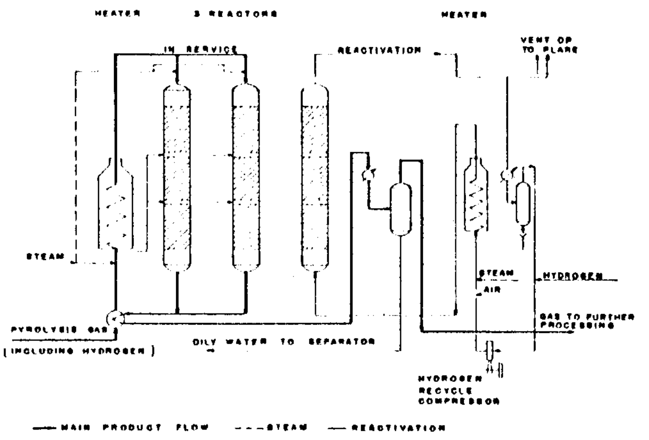
After leaving the quench tower the cracked gas is ready for compression, a process which again is complicated by the presence of condensible hydrocarbons. To prevent the polymerization of heat-sensitive constitutents, and to permit removal of condensate the compression is conducted in three or four stages with interstage coolers and separators.

Compressors may be either reciprocating or centrifugal types and the choice between them is fairly simple. Economics can usually be shown to justify the centrifugal machine in plants large enough to produce over 100 million pounds of ethylene per year. In the case of reciprocating machines, spares are usually provided so that maintenance of compressors can be carried out without shutdown. With centrifugal machines maintenance is a much more elaborate job. It occurs less frequently and shutdown is the expected arrangement for doing it.

4. Removal of Trace Impurities and Water must also be accomplished before fractionation. Somewhere in the compression cycle, perhaps between the third and fourth stages, it is usual to give the compressed gas a caustic wash even if the feed was free of sulfur compounds. This is because some carbon dioxide is formed during the cracking process.

The next step is the removal of acetylene. This may be done by catalytic hydrogenation in which case the preceeding caustic wash is also essential for the protection of the catalyst from the poisoning effect of acid gases. There are other methods of re-moving acetylene based on solvent absorption. However, hydrogenation processes have become so well developed and hydrogenation catalysts so selective that this is the dominant process. The amount of acetylene present often falls in the range of 2000-4000 parts per million. It depends upon feed stock, steam dilution, and cracking severity. Increasing the feed molecular weight or cracking at either higher steam dilution or higher severity tend to result in more acetylene.

ACETYLENE HYDROGENATION



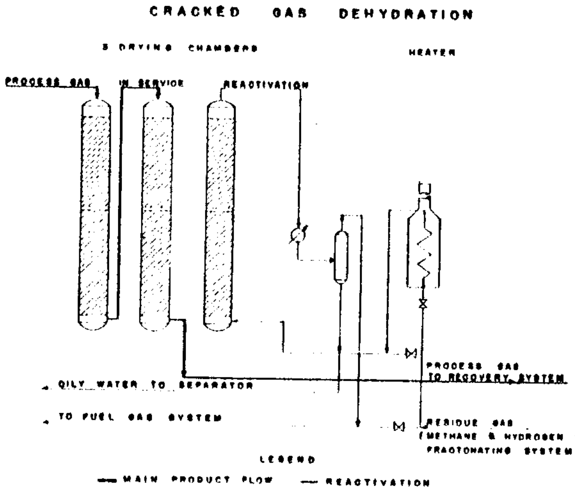
SOURCE H. C. SCHUTT & S. B. ZDONIK — MAKING ETHYLENE, A SERIES OF SIX ARTICLES IN THE OIL & GAS JOURNAL 1956

FIGURE 11. Acetylene hydrogenation

A typical acetylene hydrogenation system is shown in Figure 11. The hydrogen used in the regeneration may come from the residue gas or demethanizer overhead. Compressed pyrolysis gas is preheated and, in the example shown, passed through two parallel reactors where the hydrogen constituent of the mixture is caused to react with the acetylene. Some of the acetylene is converted to ethylene and some to ethane. An incidental small amount of ethylene is also converted to ethane. In the reactivation stage the catalyst is first treated with superheated steam to remove volatile polymers, then with hot air to oxidize tarry material and finally with hydrogen to restore the original activity. In some plants acetylene conversion is carried out on the C_2 cut rather than on a pyrolysis mixture. This gives a smaller stream to process but may require further separation of excess hydrogen.

Water is normally removed from the compressed pyrolysis gas mixture after the acetylene and when the whole compression cycle is accomplished. The usual technique is to use fixed bed solid desiccants. This dehydration is a particularly critical matter in the low temperature fractionation which usually follows. In that step ice formation can be a hazard of major proportions so that continuity of operation demands good drying. The selection of a solid desiccant is based on these criteria (1) delivered cost (2) moisture adsorption capacity (3) stability during repeated regeneration and (4) absence of tendency to cause extraneous reactions such as polymerization.

Figure 12 shows the equipment required for dehydration. The gas being dried flows through two drying chambers in series. The third chamber is being regenerated by having passed through it a stream of heated residue gas, i.e. methane and hydrogen from the fractionation system, which after re-cooling and water separation goes on to the fuel gas system. The necessary piping manifolds are provided to put each chamber through the cycle.



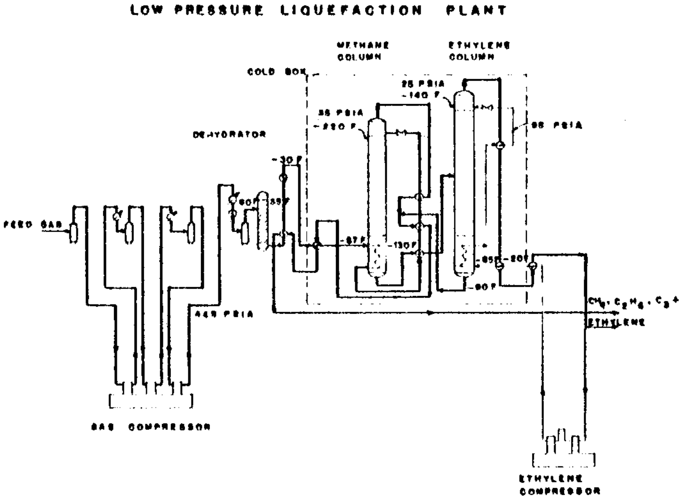
SOURCE H. G. SCHUTT & S.B. ZDONIK – MAKING ETHYLENE, A SERIES OF SIX ARTICLES IN THE OIL & GAS JOURNAL 1956

FIGURE 12. Cracked gas dehydration

5. <u>Product Fractionation</u> is the final processing step in olefin manufacture. There are four important procedures available for separating ethylene from the mixture of gases which has been compressed (depending on which process is intended, to pressures in the range of 200-500 psig) and dried. With modifications and in combination, the same procedures can be used to separate concurrently produced propylene and other olefins. These four procedures are: Low Pressure Liquefaction Plant, Absorption in Lean Oil, Adsorption on Solids and High Pressure - Low Temperature Distillation.

a. Low Pressure Liquefaction Plant

In this type plant the techniques which have been developed for liquid air production and nitrogen-oxygen separation are adapted to mixtures of hydrogen and hydrocarbons from the cracking furnace. Figure 13 shows a schematic flow sheet. It is apparent that the term "Low Pressure" refers to the fractionation equipment located in the cold box because a substantial amount of initial compression is employed. While it is necessary to remove the acid gases as already described, this unit can be designed with its own dehydration system based on water vapor freeze out followed by a melting cycle. As in air processing, the whole separation is based on low temperature equilibrium separations using combinations of close approach exchangers on the feed and products and aided by the use of Joule-Thompson expansion or engine expansion of the residue gas for producing extremely low temperatures. Plants of this type have been common in countries like Germany where liquid air industry historically was more prominent than oil refining industry. With so much inter-dependent heat exchange they are rather sensitive to variations in entering gas composition which of course do not occur when processing air.



LOW PRESSURE LIQUEFACTION PLANT

SOURCE: H.C. SCHUTT & S.B. ZDONIK — MAKING ETHYLENE, A SERIES OF SIX ARTICLES IN THE OIL & GAS JOURNAL 1956

FIGURE 13. Low pressure liquefaction plant

b. Absorption in Lean Oil

This is a characteristic procedure for getting rid, under proper conditions of operation and control, of hydrogen and methane in a gas mixture. For such an operation the most important piece of equipment would be called an absorber demethanizer. It is a hybrid absorption and reboiled distillation tower specifically designed for the split between methane and ethylene as key components, the overhead being rejected as fuel gas.

On the other hand, the absorption step in plants producing a mixture which involves large quantities of C_4 and heavier products can function in the opposite sense by taking the desired rather than the rejected products overhead. In such an installation an absorber depropanizer would be the first processing column. Its overhead gas phase would contain the valuable ethylene and propylene constituents and all lighter materials. This overhead stream would be sent to subsequent dehydration, compression and low temperature processing.

In each of these cases it is apparent that although absorption in lean oil together with subsequent stripping of the absorbate and recirculation of the lean oil is a procedure that has more than one mode of application, the name doesn't describe any full-blown scheme for making product without the combination of one of the other product fractionation procedures.

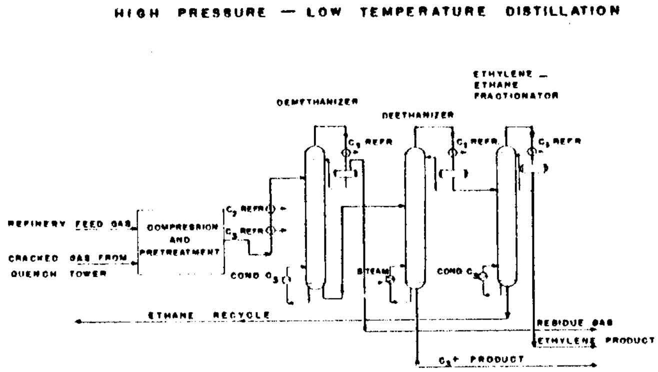
c. Adsorption on Solids

Although it has not been very widely used in the separation of olefins for commercial petrochemical production, this procedure is recognized as having possibilities not so much in, say, the separation of ethylene from ethane as in substitution for other types of demethanization i.e. making the split between methane (with accompanying hydrogen) and ethylene (with accompanying C_2 and heavier compounds). Such plants have had some success, particularly when the methane and lighter constituents are present in unusually large quantities. To make such a process continuous requires that the adsorbent be stripped of everything it picks up. Accordingly, higher boiling and polymerizable materials in the feed would present a hazard because they can permanently gum up the adsorbent. The most widely used adsorbent is activated charcoal. While it could be employed in fixed beds, petrochemical industry practise has not done so. A gravity flow moving bed process carries the trade-name Hypersorption and was developed by Union Oil of California. A fluidized char system has been developed by Esso Research and Engineering.

As in the case of absorption in lean oil the name adsorption on solids doesn't describe any general scheme for making olefin product without the combination of one of the other product fractionation procedures.

d. High Pressure - Low Temperature Distillation

At the present time this is the most important olefin product fractionation procedure and the name, with good logic, can be said to describe a practical full-blown scheme for making product. It is the procedure most consistent with the practises of the oil refining and natural gas industries and, incidentally, the procedure pioneered by my employers, Stone & Webster. For simplicity's sake Figure 14 shows an ethylene plant in which propylene and heavier compounds are not produced in sufficient quantities to warrant their separation. However, it would be easy to visualize conventional distillation columns for that purpose because, for example, in the C_3 and heavier part of the plant the condensers would involve no refrigeration. High pressure - low temperature distillation plants can be designed to accommodate a very wide range of feed stock and cracking severity conditions.



SOURCE: H.C. SCHUTT & B.B. ZDONIK—MAKING ETHYLENE, A SERIES OF SIX ARTICLES IN THE OIL & GAS JOURNAL 1956

FIGURE 14. High pressure - low temperature distillation

The demethanizer is the first tower in the series and the one that operates under the most severe conditions. Pressure in the order of 500 psig and a condenser temperature of about -140°F. are indicated for such a tower. It must be built of nickel bearing alloys and the condenser refrigerant is ethylene for which a closed circuit system is required. The ethylene condenser, in which circulating refrigerant itself is condensed, is cooled with the propane refrigerant which is also employed for cooling in the condensers of the other processing towers shown in Figure 14. This inter-relationship between refrigeration systems is termed "cascade" refrigeration. In terms of relative volatility, methane and ethylene are easy to separate. Only a few trays are required above the feed plate but about 20 trays are employed in the stripping section for methane elimination. Tower bottom temperature is usually below 65°F. and the reboiler has the dual function of being a high pressure propane refrigerant condenser.

In connection with improving the recovery efficiency by preventing ethylene escape overhead, the high operating pressure makes it possible to employ Joule-Thompson equipment or Turbo-expanders to produce a recycle liquid fraction rich in ethylene.

The deethanizer is the second tower in the series. It operates at about 380 psig. The split between C_2's and C_3's requires 30 to 40 trays and a reflux ratio of about 1. The condenser is propane refrigerated and temperatures are moderate enought to allow carbon steel construction. However, starting with this tower, attention must be paid to potential polymerization problems in the tower base and reboiler equipment. This polymerization is a consequence of overheating, either locally due to high steam pressure on the steam side of the reboiler or generally due to a tower operating pressure that requires the bottoms to boil in a heavy thermal polymerization range. Such fouling is never prevented completely but it can be kept under control by proper attention to design and operating temperatures.

The third and final tower in Figure 14 is the ethylene-ethane fractionator often called a C_2 splitter. When it is remembered that purities of 99.8% or higher are normally required for ethylene, it will be appreciated that this is a fairly high precision separation. In fact, additional towers termed ethylene rectifier and secondary demethanizer are employed in some plants in order to reach the high purity ranges. In the C_2 splitter the pressure is about 280 psig and about 60 trays are employed using reflux ratios in the order of 3.5 to 5. With a bottom temperature of 20°F. it is again possible to use the reboiler as a propane refrigerant condenser. If ethane is recycled to cracking, it is possible to tolerate in it an appreciable ethylene content which, in effect, goes along for the ride back through the furnace.

These are the essential features of high pressure - low temperature distillation without going into the full pattern of exchangers designed for heat or refrigeration conservation, the pumps, the piping, the instrumentation and other important but more or less conventional components.

D. Storage and Transportation

1. The Dominant Problem in the storage and transportation of olefins, quickly resolves itself into the storage and transportation of ethylene because propylene and heavier hydrocarbons are conveniently handled in the liquid phase at ordinary ambient temperatures and fairly moderate pressures.

Ethylene, on the other hand, is the largest tonnage olefin and the one whose storage and transportation require special attention. Ethylene's critical point is 50°F. and 51 atmospheres so that in practice non-refrigerated liquid storage is out of the question. Three different modes of storage can be employed:

(a) in tanks as a high pressure gas
(b) in tanks as a low temperature liquid
(c) in underground formations as a high pressure gas.

2. High Pressure Gas Phase Storage in tanks on a plant site is an expensive proposition. It is comparable in cost to storing oxygen or nitrogen gas. Considering the other types of installation available, it is very unlikely that any major storage installation would adopt such tanks as its basis for operating.

3. Low Temperature Liquid Phase Storage can be provided conveniently at an ethylene plant site since an ethylene fractionation system involves the correct levels of refrigeration. This type of storage is further subdivided into categories depending on the pressures and structures employed.

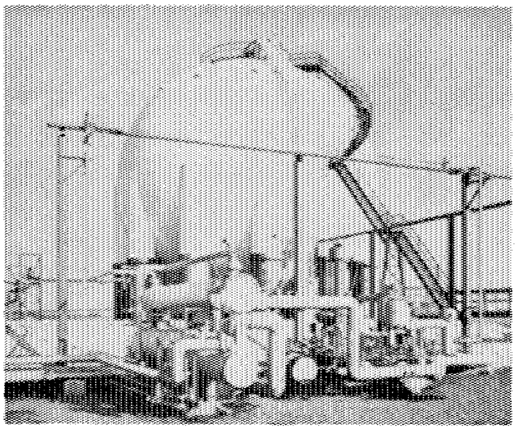
a. High Pressure Tanks

An ethylene liquid storage tank operating at a pressure of about 16 atmospheres will have a temperature of -35°F. which is conveniently attainable with propane as the refrigerating medium -- the same medium employed in the deethanizer and C_2 splitter tower condensers of a high pressure, low temperature fractionation plant.

b. Low Pressure Tanks

An ethylene liquid storage tank operating at a pressure of about 1.6 atmospheres will have a temperature of -140°F. which is conveniently obtainable with ethylene as the refrigerating medium -- i.e. it could be integrated with the demethanizer tower refrigeration system when using high pressure - low temperature fractionation. Figure 15 shows a picture of a commercial installation of this type which has a capacity of 20,000 barrels. In a congested and highly industrialized region where storage is required on the plant premises, this is most attractive.

LOW TEMPERATURE LIQUID ETHYLENE STORAGE



SOURCE STONE & WEBSTER AD "ESSO BAYWAY"

FIGURE 15. Low temperature liquid ethylene storage

c. Low Pressure Earthen Pit

A very novel way of storing a low temperature liquid has been employed recently in Lake Charles, Louisiana. There liquefied natural gas has been stored in a pit at surface level using frozen earth as the tank walls (Ref. 11). In addition to the hole and the liquefied gas, the necessary refrigeration system, an insulated roof and piping connections are required. With suitable soil conditions it is claimed that such an installation is both cheap and effective.

4. Underground Storage is a convenient operation if the geology of the region is favorable (salt domes for example). In this way it is possible to retain stocks of ethylene as a finished petrochemical intermediate at a moderate to high gas pressure. The only contaminant which users of such underground storage usually have to contend with is water vapor and this can be dealt with in conventional gas dehydration equipment.

5. Pipelines for Olefins are in commercial operation between producing and consuming plants. Where the volume of business is sufficient, this is surely an economic way of handling ethylene. In the Texas gulf coast region an extensive system of this type is in commercial operation serving a number of consumers.

6. Refrigerated Tank Carriers have been used to transport ethylene between Sarnia and the Montreal area. These are insulated highway trailer tanks carrying low pressure, low temperature liquid ethylene. This is the only really practical alternative to pipelining for short hauls and has no competition even from pipelines for long hauls of moderate quantities in regions where there are no intermediate location consumers. The application cited arose at least in part out of a temporary surplus of ethylene in the Sarnia area and so it may not represent a long term economic proposition. The basic technique involved in refrigerated tank carriers has been extended to the liquefaction of natural gas, predominately methane, and its transportation in sea-going ships with insulated, atmospheric pressure tankage. Because of the lower temperatures involved this is more difficult than transporting ethylene and therefore illustrative of the even more extensive use which can be made of low temperature liquid technique.

From the above it is seen that, while ethylene is not the most difficult gas to store and transport, it does require fairly elaborate facilities, the cost of which must be justified by volume of business.

CONCLUSIONS AS TO MOST ADVANTAGEOUS PROCEDURES

A. Market for Olefins

Having reviewed in some detail a number of olefin production problems and the available alternative solutions, the speaker is now eligible to draw some well reasoned conclusions or, failing that, to unveil a crystal ball. One rather sly conclusion that an olefins man can announce to his fellow speakers is that, since olefins are intermediates, their markets depend upon petrochemical end-products and therefore this part of the subject belongs to the other speakers. It is intended to take a more responsible attitude.

When we were exploring marketing alternatives, reference was made to captive, custom and merchant olefin markets. Considering the risks involved and considering the present size of the whole market, the order of likelihood of construction of new olefin plants in Alberta can be expected to be: captive - most likely, custom - intermediate and merchant - least likely. This order will change as industrial patterns change but its sequence is correct today.

It is often heard that prospects for profitable sale of western petrochemicals east of the Lakehead are not at all attractive as long as an excess petrochemical potential exists at Sarnia. There is surely some truth in that statement and any new venture in the West should be undertaken only after studying what it would be like to try the same operation in Sarnia. If every such check gives a negative result to Western ventures, this present meeting is a group of voices crying in the wilderness. I can't tell you which products or processes will check positive but the list is surely going to grow longer with every passing year. These are my very general conclusions on markets.

B. Feed Stocks

As was stated at the beginning of our discussion of feed stocks, the selection of the most advantageous one is clearly a matter of economics. Since we have almost every kind of feedstock imaginable here in Alberta, it might take a lot of economic study to really decide. We have already come to the conclusion that the most likely next ethylene plants to be built in Alberta would be small and captive and not in oil refineries. If this is so, ethane is a most logical raw material and the plant should be located near enough to an important natural gas processing plant so that no substantial capital would be tied up in transport facilities between the point where ethane and L.P.G.'s are separated from the natural gas and the point where ethylene is made and used.

It may be possible that a long term contract can be negotiated for the supply of some hydrocarbon not ethane at a price that, even with lower yields of ethylene, would be attractive. Such attractiveness could very well depend on the sale of by-products including propylene. That is as far as a generalized statement can go. It remains for the interested parties to tackle the economics, not of general cases but of particular propositions.

C. Techniques for Conversion & Purification

If ethane is the feed stock, the logical conversion process is a straightforward, high severity, high yield operation using a tubular fired heater. For other feed stocks our choice of cracking processes has a certain amount of additional latitude. Nevertheless, if one observes the trends in world-wide olefin production, it is apparent that the tubular fired heater is preferred today for practically all feed stocks. With increasing feed molecular weight the high severity-low severity question also demands an answer. That answer again will be based upon economics. If all by-products go to fuel, high severity is the solution. If by-products can be sold for good prices low severity may be shown to hold advantage.

When it comes to fractionation and purification we can also look at world-trends in olefin production. They clearly lead to the conclusion that the high pressure-low temperature distillation techniques based on the patterns established in oil refining and gas processing are now most widely employed. In Alberta this apparent preference should be reinforced by the existence of so many oil refineries and gas plants in our region which means that design, construction, operation and maintenance will all be made simpler by following the conventions of related industry.

D. Storage & Transportation

In the immediate future and although we have salt deposits that might make underground storage places, the most advantageous storage installation for large quantities of ethylene would probably be the low pressure, low temperature insulated spherical vessel shown in Figure 15. In a captive plant this would simply be a surge tank and the nature of succeeding process steps would regulate the size required. Quite logically a consuming unit that requires a lot of time and effort to line out at every start-up deserves more storage than a consuming unit that does not.

When it comes to transportation of ethylene as such, it is unlikely in the immediate future that there will be very much. This is because captive or geographically adjacent plants are more likely to be installed. On the other hand, the precedent set by over the road insulated tank trucks between Sarnia and Montreal is of some interest to producers who may have temporary excess supplies of ethylene for sale. Pipelines for ethylene or other olefins are, in the series of events here visualized, the last transportation facility to be required when markets have become very large and diversified.

E. Closing Remarks

Gentlemen, these are all the conclusions I have today. In a number of instances I have pointed to a problem, told you the solution is a matter of economics and then not worked the economics out for you. There are two reasons for this. First, many of the variables are not public knowledge but are internal or negotiated figures and second, the explanation and justification of detailed economic calculations would not lend themselves to a symposium type of presentation. It has been a pleasure to speak to you and I hope you have found my remarks, despite their limitations, useful and provocative of further study and discussion. I would like to record my appreciation for the interest and enthusiasm which the Research Council of Alberta has put into the organization of the present program and to acknowledge my indebtedness to the authors cited in the references and to my associates in Stone & Webster.

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CARBON BLACK TECHNOLOGY

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INTRODUCTION

As a principal member of the family of industrial carbons and one of the oldest petrochemicals, carbon black has reached an important status among the industrial products derived from natural gas and petroleum.

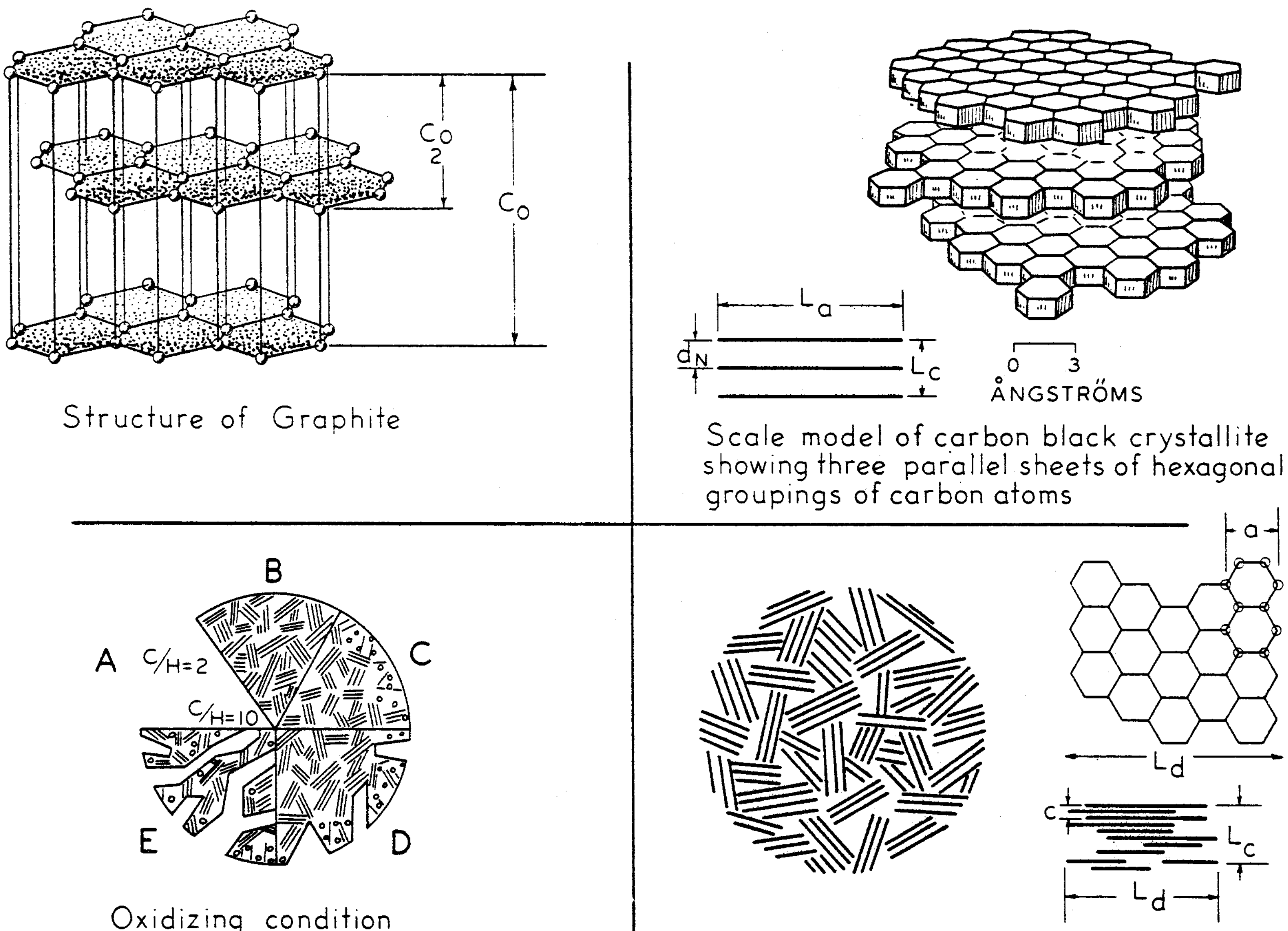
Its development and successful use as a reinforcing agent in natural and synthetic rubber and also as a valuable pigment for enamel, lacquers, paints and (printing) inks has followed the general technical progress of our age and in particular the tremendous development of the automotive industry.

The purpose of this paper is to present a brief survey of the principal processes used for manufacturing carbon black, to consider some aspects of the technology of carbon black, and to examine the conditions under which a carbon black industry may develop in Alberta.

The interest of the Research Council in carbon black extends over a period of ten years, during which studies have been carried out in co-operation with the Department of Chemical Engineering of the University of Alberta relative to various industrial pyrolysis processes - some of which have included the production of carbon black from liquid and gaseous hydrocarbons. These studies are described in separate publications (1,2,3,4,5). This review will be confined to technology in present use and as such supplements and extends a previous review by Wanat, Quon and Govier (3) which dealt principally with the manufacture of carbon black from natural gas.

Definition of Carbon Black

The term "carbon black" designates a whole class of industrial carbons obtained in finely divided form, by the incomplete combustion in a flame or by thermal decomposition of carbonaceous substances, mainly mixtures of liquid or gaseous hydrocarbons.



Structure of Graphite

Scale model of carbon black crystallite showing three parallel sheets of hexagonal groupings of carbon atoms

Oxidizing condition

(after C.W. Snow et al)

Carbon black crystallites

(after "Columbian Carbons)

FIGURE 1

We may define carbon black as a solid consisting predominantly of quasi or pseudo graphitic carbon of average particle size in the colloidal range (5 to 500 $m\mu$)(6) - the name "colloidal carbon", in fact was proposed in 1934 by Weigand for carbon black and has the merit of suggesting the property of surface development due to extreme subdivision and fine particle size (7, 8). From this definition we have already a general concept of the structure of carbon black. Quasi or pseudo graphitic structure refers to the turbostratic arrangement of the crystallites of carbon black in contrast with the regular symmetrical graphitic arrangement (Fig. 1).

We may represent the carbon black particle as the resulting aggregate of some 1500 crystallites, each of these generally containing two to five parallel sheets of hexagonally packed carbon atoms in random orientation. A certain percentage of amorphous or disordered material is present in the spaces between the crystallites(9). Schematically this disordered or turbostratic arrangement is shown in the lower right corner of Fig. 1. The lower left diagram of Fig. 1 illustrates the model of a carbon black particle in which the various phases of partial oxidation of the surface are shown. There is evidence that the edge atoms are preferentially attacked(10) and the oxidation continues through these crystallites opening up internal pores and increasing the surface area without changing appreciably the particle diameter. It is this large surface area of the particle and some other chemical properties of the surface which are actually responsible for the high reactivity of carbon black in bound rubber formation.

Classification of Carbon Blacks

Since most of the important properties of carbon black vary within a relatively wide range, making possible the existence of many types and grades of product, it is convenient, before discussing properties, to mention briefly how these various types have been classified and what nomenclature has been adopted in designating them.

A traditional classification, which groups carbon blacks in 5 classes, according to the process by which they are manufactured is shown in Table I. Each process produces carbon black of a particular type. A further sub-division of furnace processes is usually made into two broad subclasses: the gas furnace and the oil furnace.

A more detailed classification, which can include in total some 17 or 18 types is shown in Table II. Each grade of product is designated by a symbol of 2 or more letters in which the first letters indicate the two main industrial uses of the pigment by the rubber and paint industries. The terminal letter of the symbol refers to the manufacturing process.

Properties of Carbon Black

Having classified the various types of carbon black we can now discuss some of their most common properties.

SOME PROPERTIES OF CARBON BLACKS

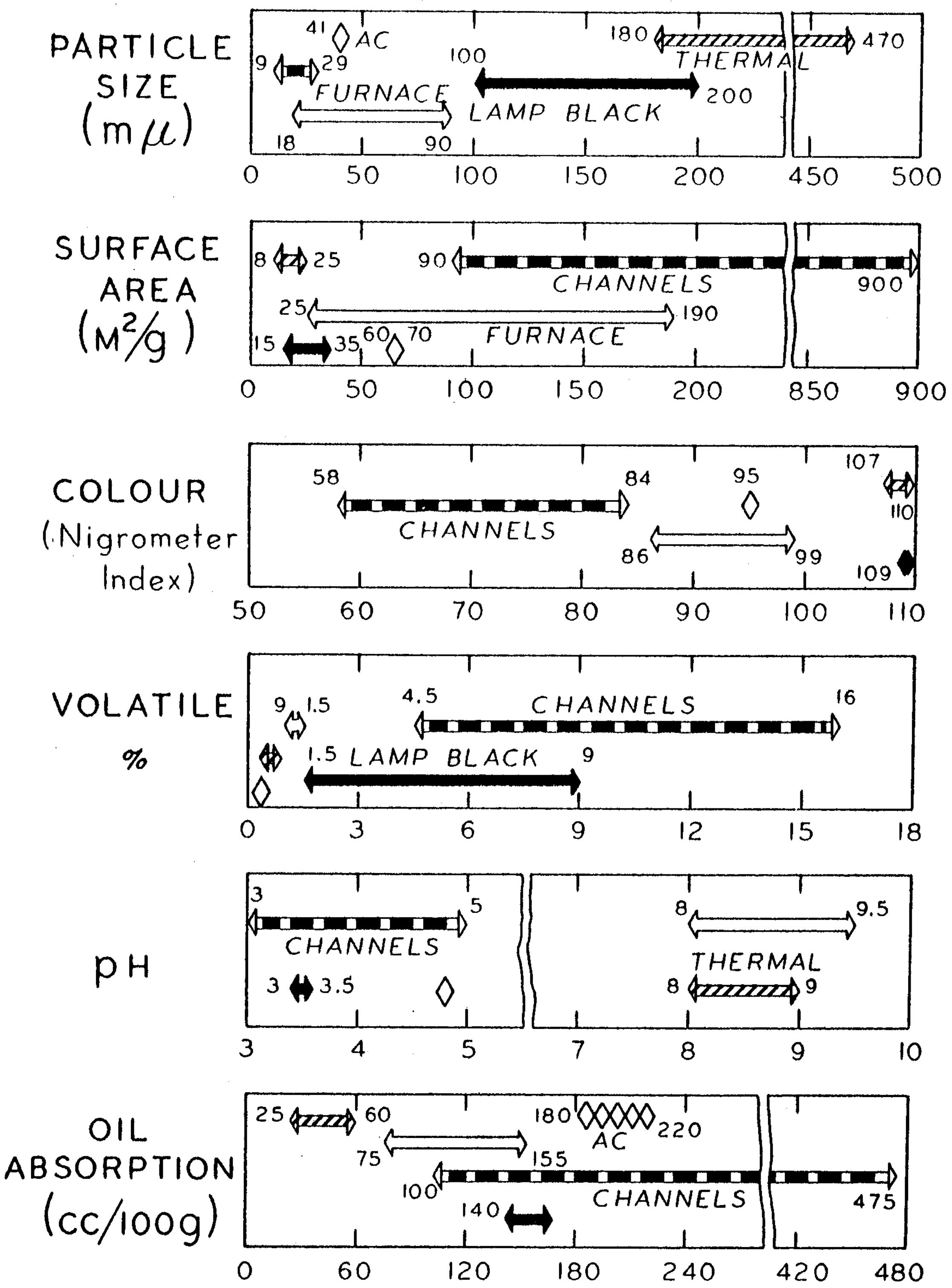


FIGURE 2

In external appearance carbon black looks similar to any common soot: a fluffy black powder of very loose texture and extremely low apparent density of 2 to 6 lbs. per cu. ft. when produced. The colour varies from a dark greyish to an intense jet black.

Some of the important properties of carbon black related to its use as a reinforcing agent in rubber and colouring pigment in inks and paint are listed in Table II and illustrated in Fig. 2. The respective range of variability is indicated as a spectrum for each of the 5 main types. Now shown in Figure 2 are some other properties such as "structure" defined as the tendency of the particles to agglomerate. This property plays an important role in rubber compounding and is measured by correlating some 2 or 3 physical and chemical properties of the carbon black particle. Chemical composition, particularly of the surface of the particle, is also important and refers mainly to hydrogen, oxygen, sulphur and ash content.

MANUFACTURE OF CARBON BLACK

Formation of Carbon Black

Since the time of Davy it was known that carbon particles have been the cause of luminosity of flames. Common soot, which is actually a type of carbon black, is formed in luminous flames and it can be collected even from a non-soot-forming flame by passing a cold probe through the luminous zone. In the same way the formation of carbon black in the channel and furnace processes involves the liberation of carbon particles from flames, although in some other processes, such as thermal, the flame is not directly involved. However, in both cases carbon is produced by the thermal decomposition of a hydrocarbon and the over-all reaction may be represented by:

$$CnHm \longrightarrow nC + \frac{m}{2} H_2 \quad \pm \quad H_R \text{ Btu/mole.}$$

Intermediate steps involving chain reactions - intermediate free radicals formation, acetylene polymerization - condensation to light aromatic hydrocarbons, polycyclization of these and condensation to light oil droplets - dehydrogenation - graphitization and solid carbon particle liberation as well as several other mechanisms have been proposed by various authors. While most of these theories are not fully proven or universally accepted, they have, however, contributed greatly to our better understanding on this subject (9, 10, 11, 12, 13).

Industrially carbon black is manufactured by a few procedures from which have originated some 4 or 5 typical processes as already shown on Figure 1. This classification reflects the main features of the formative process of the carbon particle and roughly takes into account the particle size spectrum of the carbon black.

At one extreme we find the impingement processes in which carbon black is formed in thousands of small diffusion flames, impinging on a cool metallic surface (channel, roller, rotating disc). It is a process of unconfined partial combustion. The

Table I. Carbon Blacks
(classification by process)

Type	Process features	Raw material
CHANNEL	Impingement of unconfined partial combustion of diffusion flames on cool surfaces; black exposed to oxidizing temperature after is formed	Natural Gas Town Gas Hydrocarbons
FURNACE	Controlled turbulence condition confined partial combustion in refractory chambers (furnaces)	Natural Gas Petroleum distillates and residues Mixed Oil + Gas
THERMAL	Regenerative cracking in a refractory brick checkerwork (cyclic operation, no oxygen present)	Natural Gas
LAMPBLACK	Confined partial combustion, low turbulence followed by surface oxidation	Coal tar distillates Petroleum distillates & residues and various carbonaceous materials
ACETYLENE	Confined exothermic cracking of C_2H_2 (no oxygen present)	Acetylene

(After A. F. Beede & C. A. Stokes, Petroleum Processing, Vol. 9, Sept. 1954, p. 1410)

Table II. Rubber-Grade Carbon Blacks

Type	Symbol	Mean particle diam.* $m\mu$	Surface Area* M^2/g	Volatile matter %	pH	Nigrometer index
Reinforcing Carbon Blacks						
Super-abrasion furnace	SAF	14- 20	120-140	1	9 - 10	83-85
Intermediate-super-abrasion furnace	ISAF	18- 24	110-120	1	8.5-9.5	87-89
High-abrasion furnace	HAF	24- 28	75- 95	1	8 - 9	88-90
Hard-processing channel	HPC	22- 25	100-110	5	3.7-4.0	82-84
Medium-processing channel	MPC	25- 29	90-105	5	3.8-4.5	83-86
Easy-processing channel	EPC	29- 33	80- 95	5	3.8-5.0	85-87
Medium-reinforcing Carbon Blacks						
Fast-extrusion furnace	FEF	30- 50	45- 70	<1	9.0-9.5	92-96
Fine furnace	FF	40- 45	55- 70	1	9.0-9.5	90-92
General-purpose furnace	GPF	50	45	1	9.0-9.5	96
High-modulus furnace	HMF	45- 65	30- 60	1	9.5-10.0	93-96
Semi-reinforcing furnace	SRF	60- 85	25- 45	<1	9.5-10.0	98-100
Lamp	LB	100-150	13- 25	-	4	-
Conductive Carbon Blacks						
Superconductive furnace	SCF	16- 20	120	1-2	9.5	84-88
Conductive furnace	CF	24	110	1-2	9.0	86-88
Conductive channel	CC	17- 23	100-150	5	3.5-4.5	73-80
Acetylene	-	40- 55	40- 70	<1	7 - 9	92-96
Other Carbon Blacks						
Fine thermal	FT	120-200	15- 35	<1	8.5-9.5	106
Medium thermal	MT	250-500	5- 10	<1	7-9	115

* These estimates are from measurements of electron-microscope images of the particles.

Source: W. J. S. Naunton, editor: The applied science of rubber, E. Arnold, London (1961).

black once formed is exposed to an oxidizing atmosphere at a relatively high temperature for the time required to oxidize partially its surface. The grades obtained in this process have the finest particle size, with the highest surface area of the carbon black spectrum and also the highest volatile content.

At the other extreme of the spectrum we may place the "thermal" process in which carbon black is formed in the absence of air, by the thermal decomposition of pure or mixed gaseous hydrocarbons (rarely liquid hydrocarbons from petroleum residual oils) in a previously heated refractory chamber. No direct flame is involved here and the carbon once formed is not exposed to an oxidizing atmosphere. The process is discontinuous and consists of alternate "heat" and "make" (reaction) cycles. The grades produced by this process are the coarsest of the carbon black spectrum and have low surface area and low structure.

In between these two extremes we may place the various types of furnace processes which produce the wide range of gas and oil blacks and most of the valuable rubber grade carbon blacks. The furnace process may be further subdivided in gas furnace and oil furnace processes according to the nature of the raw material used and the particular features of the combustion. Thus in many gas furnace processes, combustion takes place only at the interface between layers of gas and air and the carbon black is formed in a laminar diffusion flame. In oil furnace processes, on the other hand, a turbulent flow condition is rather predominant. Both processes have in common the same features of a confined partial combustion, under closely controlled conditions of low or high turbulence and in both we may consider the furnace walls as the outer boundaries of a huge flame in which the carbon is formed(9).

The last two processes of our classification, the lampblack and the acetylene, though responsible for only a small fraction of the whole world production of carbon black are still in use and their respective products are in demand for special applications.

The lamp process, which is the oldest of the carbon black processes, and was used by the Ancients for obtaining their black pigments, consists in burning oil, coal tar residues or other carbonaceous materials, by a free flame method. In this confined partial combustion process, the carbon formed in the flame is entrained by the flue gases and allowed to settle in one or more chambers, from which it is removed periodically. The process is thus discontinuous but some U.S. patents claim continuous lampblack processes(14,16).

Acetylene black may be produced in 3 or more processes of the various thermal, furnace, electric arc or autothermic categories.

Two premium grades of acetylene black are produced in Canada by Shawinigan Chemicals Ltd., the only North American manufacturer of these grades, by a thermal furnace process in which acetylene is cracked at 800°C. Details of the process are not available.

Technical Features (sections) of Industrial Plants

The main sections of an industrial carbon black plant include: a production section, a collecting section, and a processing section.

(a) Production Section, in which carbon black is formed in some kind of hot house (channel), chamber (lampblack), or reactor (furnace). This section contains most of the metering devices required for an accurate control of the various streams of fuel, raw material, auxiliary fuels, inert gases, steam, etc. Means for injection or introduction of the various streams of fuel and raw material into the reactor are provided in many variations according to the particular requirements of each process.

The production section includes also a cooling system, often required for some parts of the furnace and equipment.

A water spraying system is added to all furnace processes, usually at the outlet end of the reactor and performs the important function of quenching the reaction of carbon formation at the desired stage for each type or grade of product, cooling at the same time the spent gases containing carbon black from 2300-2500°F. to 500-600°F.

(b) Collecting Section. Here the carbon particles are separated from the stream of combustion gases, the finer particles are agglomerated into easier handling aggregates and the black is conveyed toward the final processing stage.

The collecting system usually includes, according to the type of process, screw, belt or bucket conveyors; Cottrell electrostatic precipitators, performing mainly the agglomeration of the particles; a series of one, two or more stages of cyclones, with provision for separate primary or secondary collection; and a series of filter bags in fiber glass or fiber plastic (orlon) which perform the final stage of separation of the carbon aerosol, leaving a clean carbon-free off-gas for exhaust, recycling, or reutilization.

Some of the carbon black entrained in the slurries resulting from the quench section, scrubbers and wet precipitators is collected, separated, or recycled with the slurry back into the quench section.

In many modern furnace plants the Cottrell electrostatic precipitator has been replaced by standard cyclones and filter bag equipment.

(c) Processing Section. It may include various separate pieces of equipment of which the main functions are: agglomerating, densifying, pulverizing and eliminating grit from the final product. Common to all types of industrial plants is the pelletizing equipment, which through a series of mills, rotating drums, and driers agglomerates the fluffy particles of black into spherical pellets of higher density (16 to 24 lb./cu.ft.) which are easier to handle, pack, and ship. Dry or wet pelletizing is used according to the properties or grade of product.

In some modern furnace plants a new section for post treatment of the carbon black particle has been recently introduced, with the purpose of obtaining by oxidation or some chemical treatment, a finer particle size with higher surface area development and higher reactivity. This treatment can be performed in a separate reactor or a furnace adjacent to the production section. Technical details of the present arrangements are not available.

The technical features of carbon black processing previously described can be better illustrated by reference to particular industrial processes. Of the most important manufacturing processes we shall briefly describe here only the channel, the thermal, and the oil furnace processes.

The Channel Process

A flow sheet of this process is given in Figure 3. In the left side of Figure 3, hot buildings containing the moving channels (CH) on which the carbon black is deposited, are illustrated. An enlarged section of the channel and the lava tip burner with the impinging flame underneath the cool surface of the channel is shown in the upper left corner. The black is collected in hoppers (H) and leaves the production section through a screw conveyor (S.C.) Cyclones (CY), and pneumatic separators convey further the product to grit separating (B) agitator tank (AG.T.), pelletizing (P) and finally through a bucket elevator to storage (ST) or shipping (H.C.). A full description of this old process can be found in all technical literature on carbon black(6, 11, 12, 14, 15).

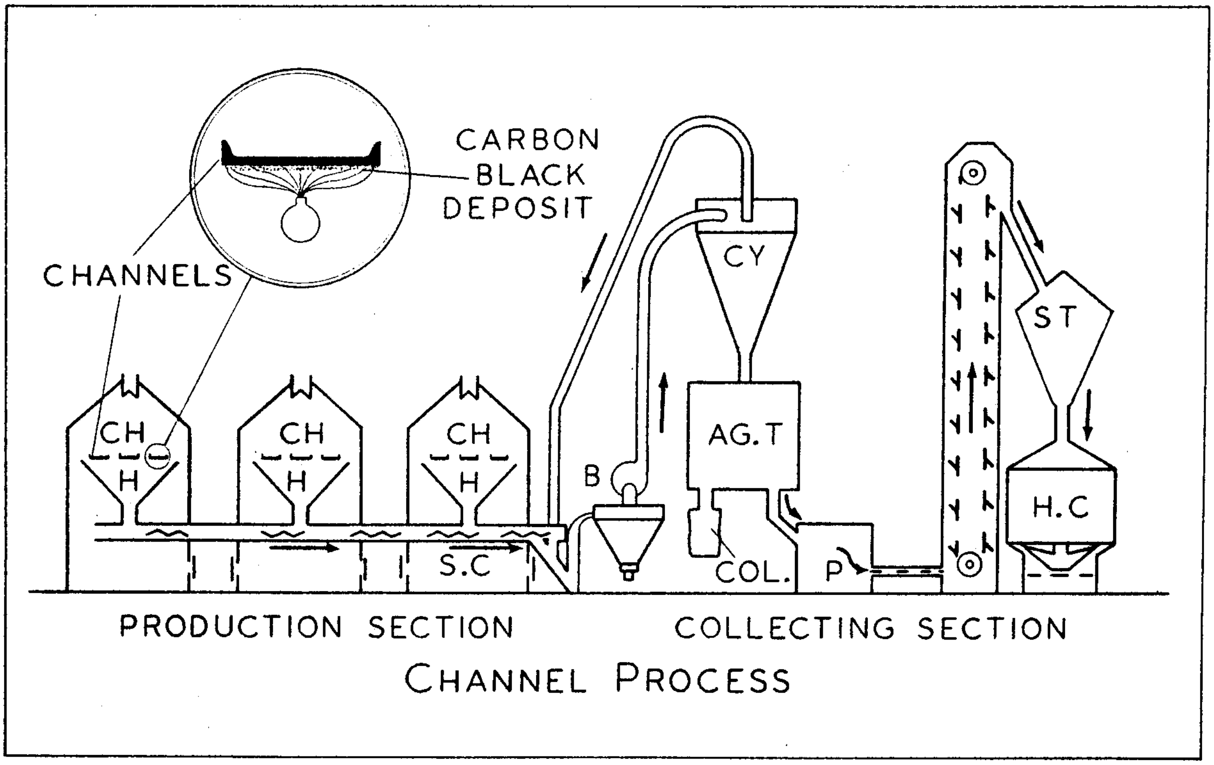
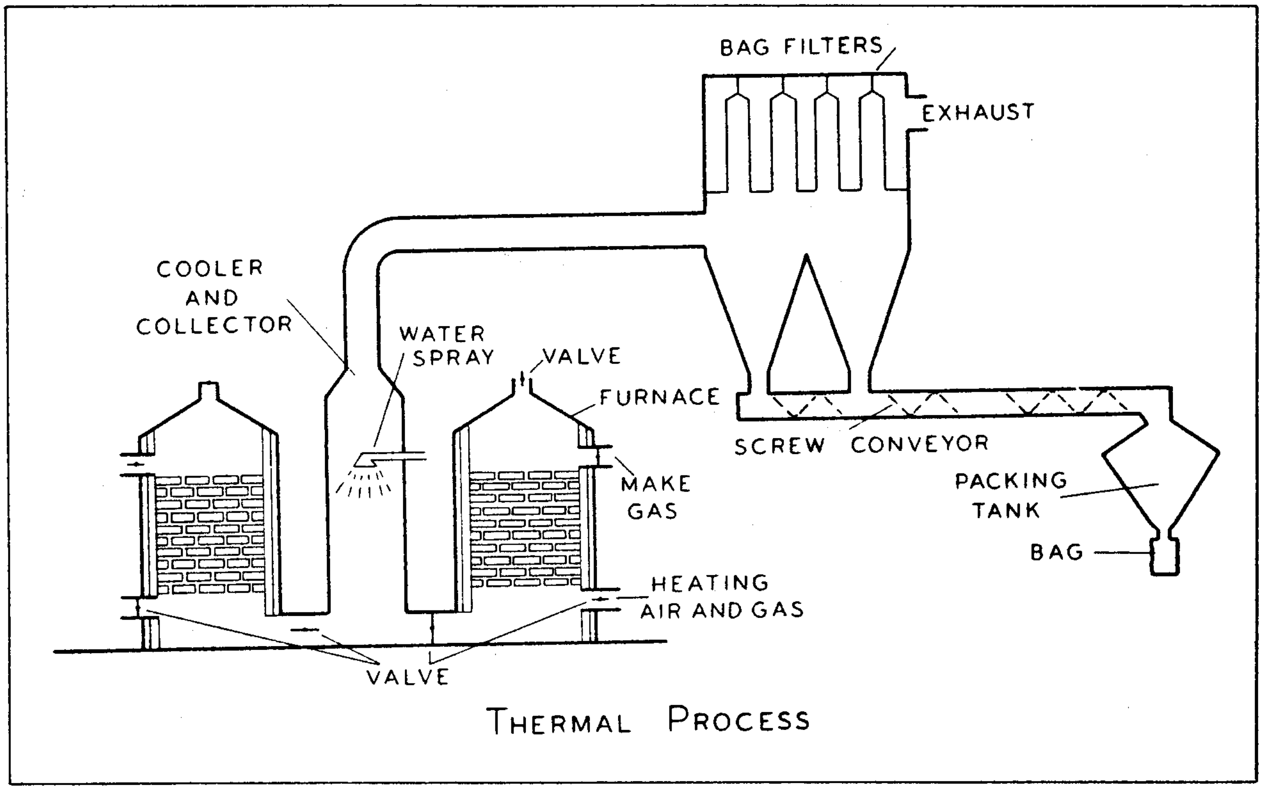


Figure 3 .

The Thermal Process

This discontinuous process in two cycles of approximately 5 minutes each is performed in two furnaces, as shown on the left side of Figure 4. The furnaces are filled with a refractory brick checkerwork, which acts as a heat regenerator, accumulating heat in the "heating" cycle from the combustion of a gaseous fuel (natural gas usually). This heat is supplied in the following "make" or reaction cycle to the natural gas feedstock, which is thermally cracked in the absence of air into carbon and hydrogen. Recycling of the hydrogen rich gases is often performed in order to improve the quality (mainly reduction of the particle size).



after: Interscience Encycl. Inc.

Figure 4.

The Oil Furnace Process

From the various gas and oil furnace processes, the Phillips oil furnace process will be described here. It has enjoyed great commercial success, because of its capacity to produce high quality carbon black in high yields (up to 60%) and is being used in the

U.S. and abroad, on license by other producers. However, the oil black process has many variations and the major carbon black companies apply some of their own patented processes.

The essential feature (Fig. 5) of this process is the tangential introduction of the fuel-air combustion mixture (usually natural gas) into the enlarged diameter inlet section (combustion section) of the cylindrically shaped reactor. A whirling mass of gas is thus created which by clinging to the walls of the cylinder prevents carbon deposition.

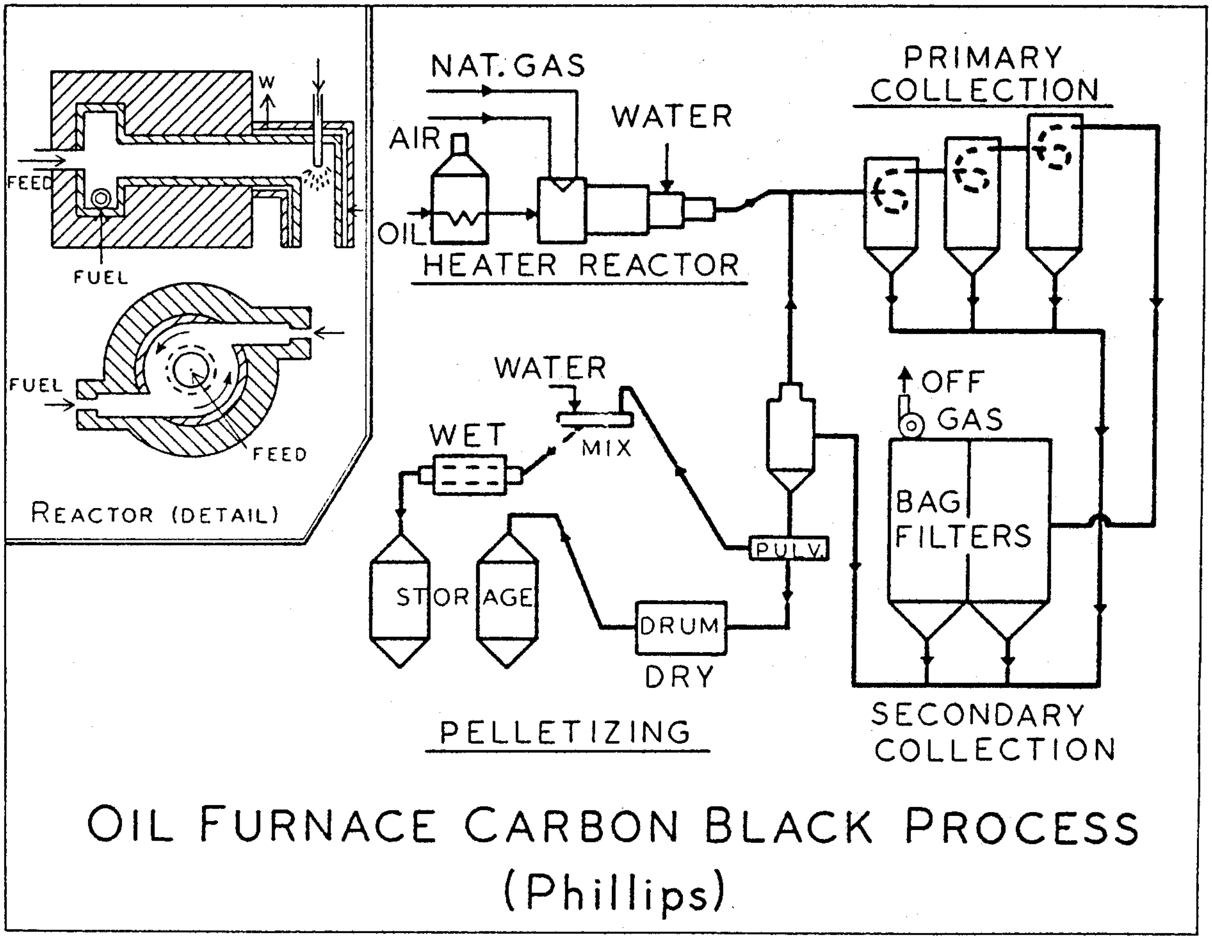


Figure 5.

The preheated feedstock, mainly heavy aromatic petroleum fractions, vaporized or finely atomized, is introduced coaxially to the length of the furnace and enters the hot hollow core left by the whirling mass of the combustion gases. It is mixed with these, and passes into the reaction section of the furnace which is of a much narrower cross section than the combustion section. It is in this section and initially in the non-rotating central core of the cyclonic flow that the carbon black probably is formed. Details of the reactor in sectional view are shown in the upper left corner of Figure 5. The remainder of the equipment contains the conventional parts for quenching, conveying, and processing as in most carbon black manufacturing processes. Pelletizing may be accomplished by a wet or a dry procedure.

Yields and Quality of the Product

In all the industrial processes previously described, the yield and the quality of the product obtained in the process are the two important elements by which the commercial value of the product and the economics of the process are evaluated. In Table III the commercial yields for various manufacturing processes are expressed in the usual units as a per cent of the theoretical carbon content. It may be seen how they vary in magnitude from the low values of the channel process to a high value of 60% in modern oil furnace processes.

Yields in carbon black production are lowered because some carbon is inevitably lost in carbon oxides and hydrocarbons which are reformed in side reactions. This loss cannot be avoided since in some processes, such as the furnace for example, the decomposition reaction is stopped by quenching at a certain stage in order to obtain the required size and surface properties of the carbon black particle. In other processes such as the channel, the same properties are obtained by oxidation of the particle after it has been formed.

Table III. Commercial Yields of Carbon Black Processes

Process	Raw Material	Commercial Yields	% Yield Carbon of theoretical Carbon Content
Channel	Natural Gas	1.0 - 2 lbs./1000 cu.ft. gas	3 - 6*
Gas-furnace	Natural Gas	9.0 - 12.0 lbs./1000 cu.ft. gas	28 -37*
Oil-furnace	Petroleum fractions	2.5 - 4.5 lbs./gallon oil	35 -60**
Thermal	Natural Gas	10 - 15 lbs./1000 cu.ft. gas	30 -47*

* Based on feed + fuel
** Based on oil feed

Quality and yield are thus closely related and generally vary inversely. In the channel process, for example, we have very low yields because we are producing here a high grade material of very fine particle size and high surface area development. In the thermal process instead, yields are quite high but quality is low, since the particles are the coarsest of the carbon black spectrum.

Technical Operating Variables

Considerable efforts, through research and development work, mostly due to the major carbon black producers, have been made in the last 20 years in order to improve yield and maintain unchanged or even improve the quality of the product.

This work has made possible the remarkable progress achieved in modern manufacturing processes and has also broadened our knowledge on the various technical factors involved in carbon black production.

These technical factors or operating variables are of great importance for any manufacturing process because they determine the technical features of the process and, by a correct balance or their right combination, the optimum conditions may be reached for producing the desired type and grades of product in economical yield.

We may consider as primary technical factors the variables of a carbon black process which by their combination in the manufacturing process determine the broad class or type of carbon black produced in a process. These are: raw material, temperature and contact time of the thermal decomposition reaction.

Raw Material - Theoretically any liquid or gaseous hydrocarbon can be cracked to form carbon black. In industrial practice, however, the selection of a suitable feedstock is somewhat more complicated. While natural gas, when available at economic prices, may be used as a raw material within a wide range of chemical compositions and will produce the corresponding various grades of channel or gas-furnace blacks, liquid hydrocarbons can be used only in a rather narrow range of properties. For economic reasons, only low-priced petroleum fractions, and in some cases coal tar distillates, can be selected as suitable feedstocks for modern oil-furnace processes. Broadly speaking, a heavy oil rich in aromatics and highly unsaturated, and with a mid-boiling point of around 500°F. is preferred(24, 26). Such an oil may be produced in some refinery cracking operations, perhaps supplemented by an extraction process. For any particular refinery the economics may depend both on the nature of the crude oil being used and on how this product fits into the over-all refinery operations.

Temperature - The temperature varies in a relatively narrow range of a few hundred degrees for most industrial processes, between 2000 and 2700°F.

Contact Time - The contact time or the duration of the thermal decomposition reaction in which the carbon particle is formed varies from a very short 0.01 sec. in channel processes to several seconds in a thermal or furnace process.

Secondary Technical Factors - Such may be called the variables of a process which are related or determine by their combination one of the primary variables. It is somewhat an arbitrary classification because one may think that some of these factors may be as important as the factors listed in the first category, as in fact they are in some cases. However, with this reservation, these other technical factors may be listed as follows, together with brief comments on their significance to the processes:

(a) Air-fuel ratios - control temperature and degree of combustion;

(b) Rate of flow of the fuel or of both fuel and feed when separately introduced - are related to contact time;

(c) Velocity and flow pattern of feedstock when introduced or after introduction in the reactor - are related to contact time and geometry of the burner and reaction chamber;

(d) Degree of mixing of feed and fuel - is related to (c) and the geometry of the reactor;

(e) Size, shape and distance of flame or burner from cooling surface or quenching area - are related to velocity and flow pattern and determine in impingement processes the size and surface area of the carbon particle;

(f) Dilution of feed or recycling with spent gases, inert gases or steam - related to size and surface properties of the carbon particle;

(g) Preheating of feed prior to thermal decomposition - related to degree of mixing;

(h) Addition of chemicals or inhibitors to modify the atmosphere in which carbon formation takes place - related to modification of surface properties and size of the carbon particle.

Future Technical Developments

To conclude this section on the technical features of the various processes, a few considerations on the future development of carbon black technology will be given.

We may say that carbon black production has reached, at the present, a stable stage of development in which by relatively few, well established processes a wide variety of grades of products can be obtained to satisfy the demands of the two major users, the rubber and paint industries, as well as those of the other minor consumers.

Technological progress or changes, however, may be expected for a rapidly expanding industry and we believe that it may develop along some of the following lines:

(a) Progress in the oil-furnace process may be expected in the direction of further extension of the range of blacks produced - particularly into the region of channel blacks. Consequently, a decline in use and slow replacement of the channel carbon blacks by these new grades with equivalent properties produced more cheaply by the oil-furnace process will take place. This may further reduce the market share of the channel black from the present 14% to perhaps lower than 8 - 10%.

(b) Thermal, lamp, and acetylene blacks will perhaps continue to maintain their modest share of the market, since, as in the case of channel, they are still used for special applications.

(c) Progress may be expected in improving yields in new processes and perhaps in some of the older ones. Progress from research and a better understanding of the carbon formation reactions will make possible a greater versatility of the manufacturing processes and the use of a wider range of carbonaceous raw materials.

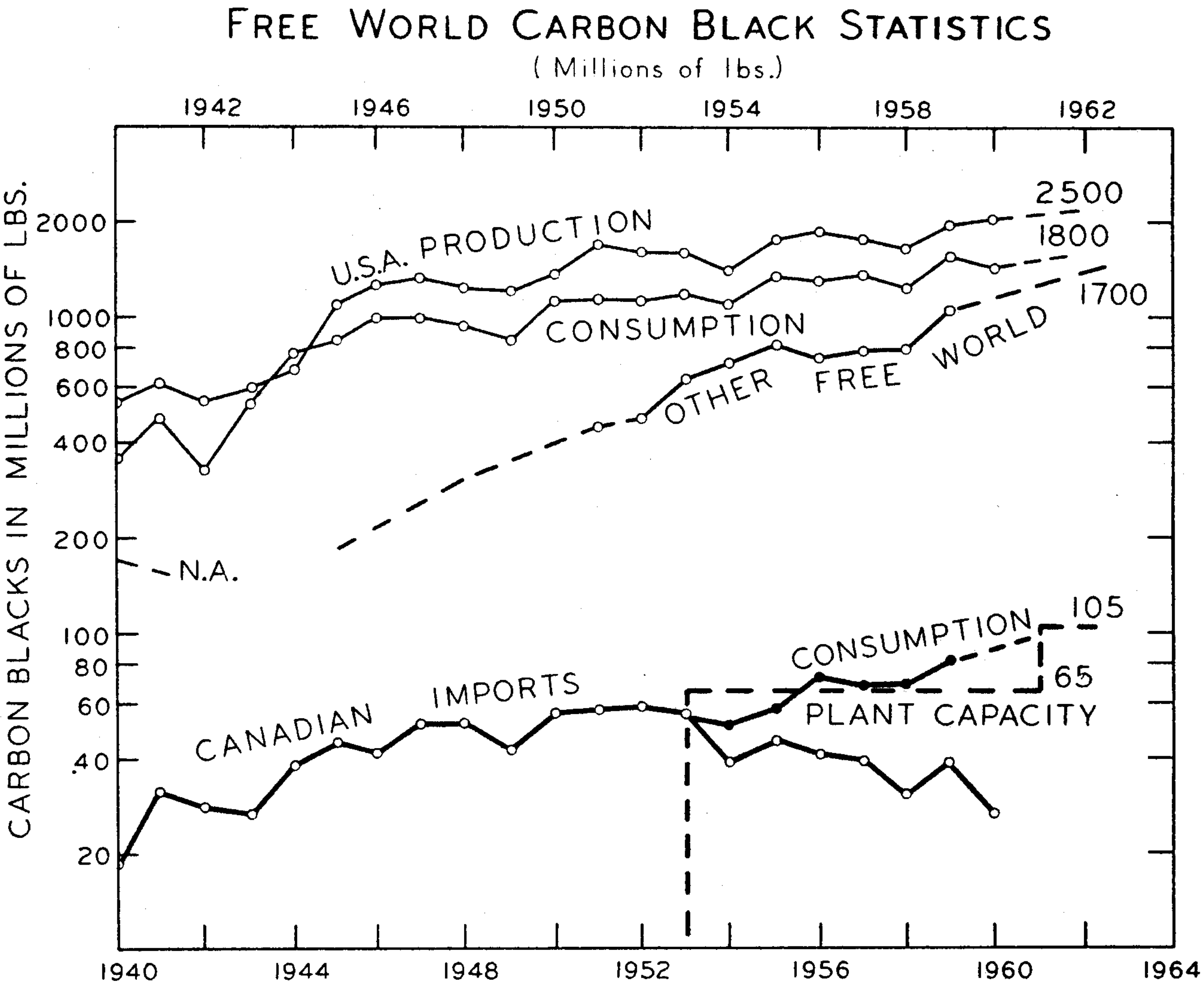
(d) A possible development of a multipurpose furnace process to make use of both oil and natural gas for relatively small volume production of a wide range of grades may be envisaged. Such a development would be desirable for Alberta. Whether or not any of the major producers are looking in this direction is not known.

ECONOMIC ASPECTS OF CARBON BLACK

Following the discussion in the first part of this paper of some aspects of carbon black technology, consideration will now be given to the present economic development of this industry.

The World Picture

The remarkable expansion of carbon black production in the last 20 years is illustrated in Figure 6. It is estimated that by the end of 1962 the free world production capacity will total some 4 billion lbs./year. The figures on the right side of the figure indicate rough estimates on production and consumption. The share of the U.S. of both world consumption and production is still large, but the U.S. rate of growth is now only 4.1% per year compared with the 10.8% per year in the free world, outside the U.S. The increased production outside the U.S., means a reduction in U.S. exports from the present figure of about 500 million lbs./year; perhaps the U.S. growth rate will decrease still further and the total production forecast of 2500 million lbs. for 1962 will not be reached(17, 18).



Sources : U.S. Bureau of Mines & Cabot estimates

Figure 6.

The Canadian Picture

The pattern of growth for Canada is similar to the general picture. Canada started to produce rubber grade carbon blacks in 1953, when, as indicated in the lower part of Figure 6, imports started to drop steadily. Recently Canada has increased her plant capacity from the initial 65 million lbs./year to 105 million lbs./year. In Table IV figures on plants and their capacity are indicated. There is also shown in this table the average size of modern carbon black plants, usually in the range of 25-30 million lbs./year, most of them using the oil-furnace process. Capital costs for construction of new carbon black plants average $200 per ton-year capacity and represent an initial investment cost of 3 to 5 million dollars for a modern plant of 30 to 50 million lbs./year capacity(19, 20, 21).

The prices of the product f.o.b. plant vary according to type and grade from 6 to 12 cents/lb. Specialty or such premium grades as acetylene black may reach 30 cents/lb.

Figure 7 shows how the prices of raw materials have influenced the switch from natural gas to heavy petroleum fractions, determining the success of the oil furnace process. Increase in liquid hydrocarbon amounts and decrease in natural gas used as raw materials are indicated for the last 8 years of the fifties.

Table IV. Plants and Capacity (1962 Estimates)

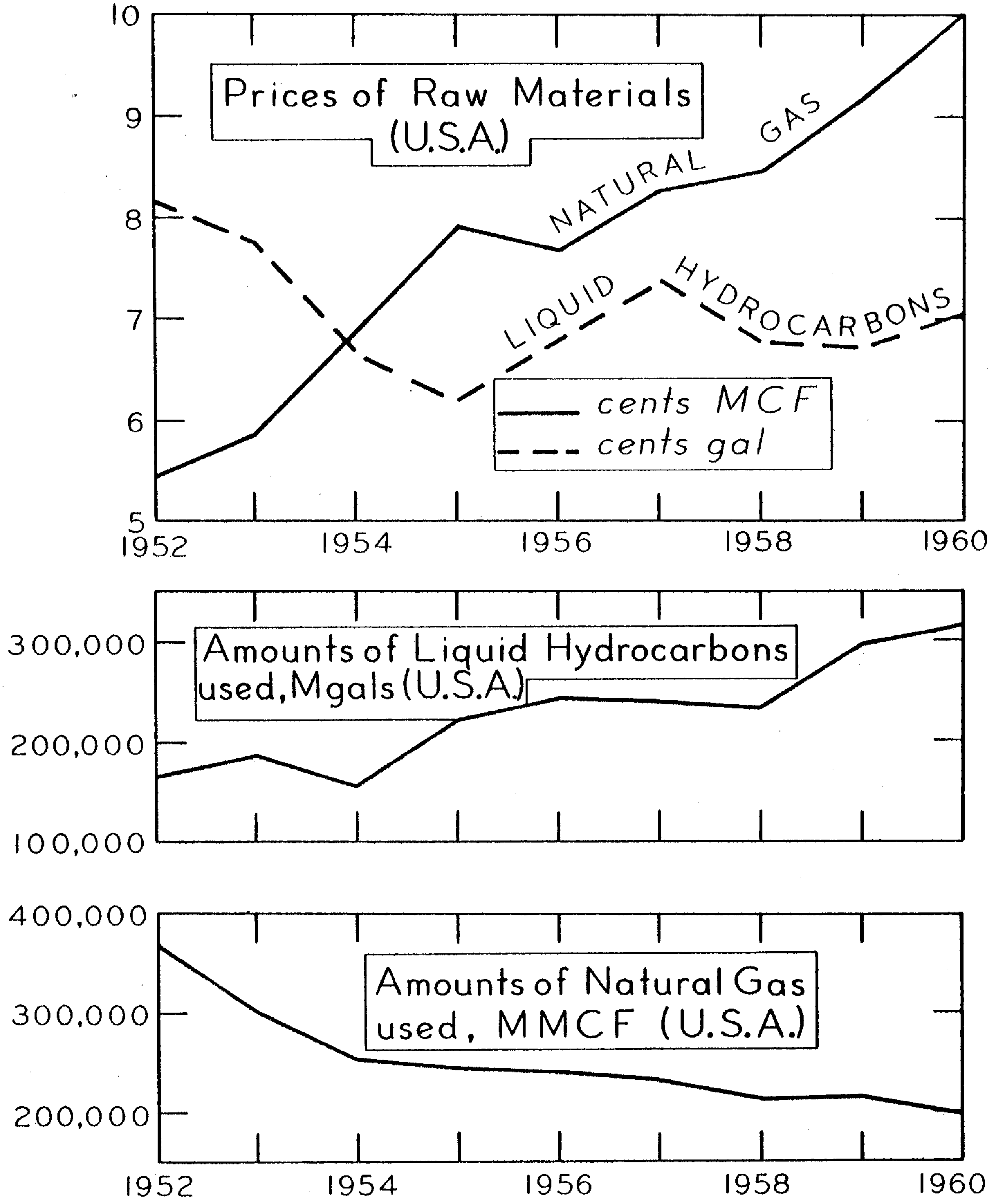
	No. Plants	MMlb./year
U.S.A.	42	2,487
Free World	24	1,501
Total Free World	66	3,988
Canada	2	105
Size of modern plants: million lbs./year (oil blacks)		20 - 60
Cost of plants: $ per ton-year capacity		160 -240
Prices of carbon black - cents /lb. (f.o.b. Canadian plant in carload)		6 - 12

Sources: U.S. Bureau of Mines

Canadian and Alberta Situation

The prospects for Alberta must be considered in the light of the North American and the world wide picture of the carbon black industry at the present. It has been asked many times: "Can we have a carbon black industry in Alberta?" "What prospects are there to develop such an industry in our Province?"

Such questions have been asked ever since Alberta became an important natural gas producer. The possibilities of utilization of Alberta Turner Valley natural gas for carbon black production were investigated in 1935 and the porous tube pidgeon process was then proposed(22) , but no industrial development followed. Later, when



Source: U.S. Bureau of Mines

Figure 7.

the discoveries of 1947 placed Alberta among the big producers of oil and natural gas there was a revival in the interest for natural gas utilization in general and carbon black production in particular. As mentioned before, some investigations were conducted by the Research Council of Alberta in co-operation with the University of Alberta(2,3,4,5) .

Prior to 1953, the year when Canada became a rubber grade carbon black producer, Cabot Carbon of Canada investigated the possibility of making carbon black in Alberta(23), but the project was dropped as uneconomic because of the long rail haul to the big eastern markets, the freight charges being too high for a relatively low-priced material. Since then, however, the situation has further modified and the establishment of two tire plants in the province has recently revived the interest in an Alberta carbon black industry.

It may therefore be useful to present a preliminary evaluation of the feasibility of such an industry in Alberta, even if complete statistics on local market conditions are not available at the present. An outline of the technical and economic considerations upon which this evaluation may be based is as follows:

Market - In Table V figures concerning the Canadian market are indicated and some estimates on a potential market in Alberta, B.C. and the U.S. Northwest are presented. These estimates indicate a demand of 3,400,000 lbs./year for Alberta which, with the addition of the potential exports to B.C. and two or three of the U.S. Northwestern States, would give a total of some 4,800,000 lbs./year for the Western region here considered. Of this total the share of the oil-carbon blacks mostly of the HAF, FEF, SRF types, for rubber use, may be 3.5 million lbs. This figure is rather modest if compared with the usual 10-fold greater capacities of eastern or foreign plants, but would represent only the beginning of a production based mainly on a local demand, with perhaps some hope of future development in an over-all picture of general industrial and petrochemical expansion. Potential exports to the Far East, at least for rubber grade blacks, are not considered here at the present since Japan, India, and Australia recently became producers of carbon black. The possibilities of producing some special and premium grades of blacks from Alberta have not yet been assessed, but they might be of interest as export commodities because their higher prices could allow for the absorption of the freight charges.

Table V. Consumption and Markets

	Thousand lbs.
Canadian consumption (1960)	67,592
Canadian imports (1960)	27,758
Present Alberta production	none
Shipments entering Alberta (1961 estimate)	3,400
Estimated consumption	
B.C. and U.S. Northwest	1,400
Market, Alberta, B.C., U.S. Northwest	
Total (1962 estimate)	4,800
Oil carbon black	3,500

Source: DES and estim.

Process - Since 60 to 70% of the rubber industry requirement is for oil-black grades, first consideration should be given to an oil-furnace process of the conventional type. However, the particular situation in Alberta - with a relatively small market but abundant raw material - may warrant a special technical and economic study for the application of a kind of multipurpose oil and gas furnace process. Technically this would be feasible with special arrangement and alternate use of various reactor units of different design. The collecting equipment and processing equipment, which are the most expensive sections of a carbon black plant, might be used in common with the various reactors.

Raw Material - The availability of raw material is also an important factor in considering the establishment of a carbon black industry. Thus natural gas, is important as a fuel and also as a feedstock in some processes. A cheap supply of gaseous fuel is therefore highly desirable.

With regard to liquid hydrocarbon feedstocks, as noted before, a rather specialized oil feed is required for modern oil blacks. While many refineries could probably produce suitable feeds, it apparently has not yet been economic for refineries in Canada or the United Kingdon to do so. Carbon black plants in both countries import oils from the U.S. There is obviously a strong incentive for refineries in Ontario to produce oils for the present Canadian plants. Since they are refining the same oils as do our local refineries, these might also produce suitable feeds once processes are worked out in Ontario, although the same processes may not be economically attractive here. Until then oils for an Alberta plant would need to be imported from the U.S.

Size of a Carbon Black Plant - As mentioned before, modern carbon black plants are usually of a large size, smaller plants under 10 million lbs. per year production capacity being considered uneconomical to operate. Any development in Alberta, therefore, would have to justify planning a factory of say 10 million lbs./year developed gradually in time and looking to future market expansion. Smaller plants are likely to be justified only by some special situation, such as an export or local demand for specialized grades or the possibility of integration of production units into some petrochemical operation in which say hydrogen may be recovered and used as a primary product along with the carbon black produced.

Conclusions

The situation for Alberta may be summarized as follows:

(a) Alberta has a market which is just starting to be attractive;
(b) Alberta has an abundance of gaseous fuel;
(c) Alberta has no local availability of oil feeds at present, but reasonably good prospects;
(d) Some development work towards a versatile oil and gas furnace process to be applied to a small multipurpose plant would be desirable; or alternatively some development work toward a small scale production of special or premium grades in conjunction with petrochemical operations, might also be of interest.

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Additional information on carbon black is available from the Librarian of the Research Council of Alberta, Edmonton, as an appendix to this paper, covering the following subjects: classification and properties of various types of carbon black; reinforcement properties and testing procedures; selection of raw materials and energy requirements for manufacturing processes; Canadian consumption patterns; and a selected bibliography.

TRENDS IN RUBBER

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The history of rubber in this century is a classic example of growth and change in reflection of man's advance to higher living standards. Indeed, the intensity with which rubber is consumed provides a rather accurate means of comparing material standards of life in one part of the world with another.

World interest in the commodity rubber is not, however, solely confined to its high degree of utility in end-products, for in the short space of twenty years, rubber has grown to the position as a major outlet for the resources of petroleum, natural gas, chemicals and other industrial products. Today more than half of the world's rubber is man-made where twenty years ago all but a small amount was tree-grown. It is certain that over the balance of this century, with the promise of population explosion and the great hopes for widespread better living, the man-directed synthesis of hydrocarbons will undoubtedly be the dominant form in which the world's rubber needs will be met.

In describing trends in rubber, this paper will deal with three broad aspects:

(1) A profile of the rubber market.

(2) Technological change.

(3) Harnessing resources for rubber.

A Profile of the Rubber Market

Over the first sixty years of this century, the world use of rubber increased at an average annual rate of 7.5 percent, in effect a doubling of consumption every ten years. As will be seen in Figure I, the growth has been somewhat less pronounced since 1930 chiefly because of the inevitable effects of several major countries passing through the formative growth stage to the position of industrial maturity. Notwithstanding it is expected that by sometime between 1970 and 1975 a further doubling of world rubber requirements will have occurred.

WORLD NEW RUBBER CONSUMPTION

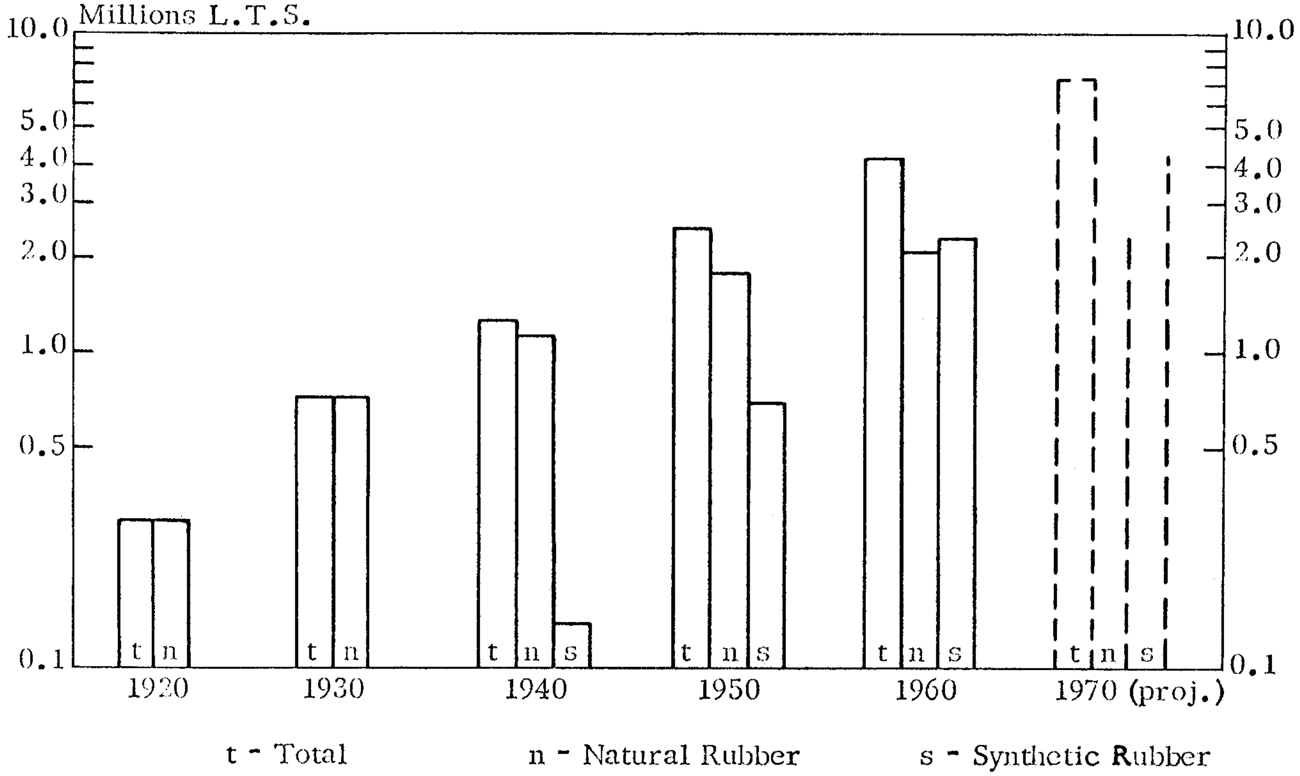


Figure 1

Figure 1also demonstrates the rapid progress which synthetic elastomers have made in two decades. It is fair to state that, initially, the impetus to synthetic supply sources was given by conditions of war, but latterly, the technical improvements in the original synthetic rubbers and the newer types of synthetic which have been developed, have provided the foundations to enable the synthetics to meet, more successfully than ever before, the varied requirements of the rubber user. Accordingly, the precise division of future rubber use between synthetic and tree-grown material is not at all clear and is so indicated in Figure 1. Suffice it to say, at this point, that there are prospects for ample supplies of both and that competition in the market place will determine the division.

A simple comparison of per capita rubber use in selected regions of the world is given in Figure 2. It highlights the fact that many areas of the world are using rubber only one-quarter as intensively as the experience in the U.S.A. These disparities take on great significance for the future. This per capita comparison, in which the U.S.A. is disclosed as the leader, gives a rough idea of the long-range potentials for growth in rubber use in other parts of the world. Disadvantages of geography and

RUBBER CONSUMPTION PER CAPITA, 1960

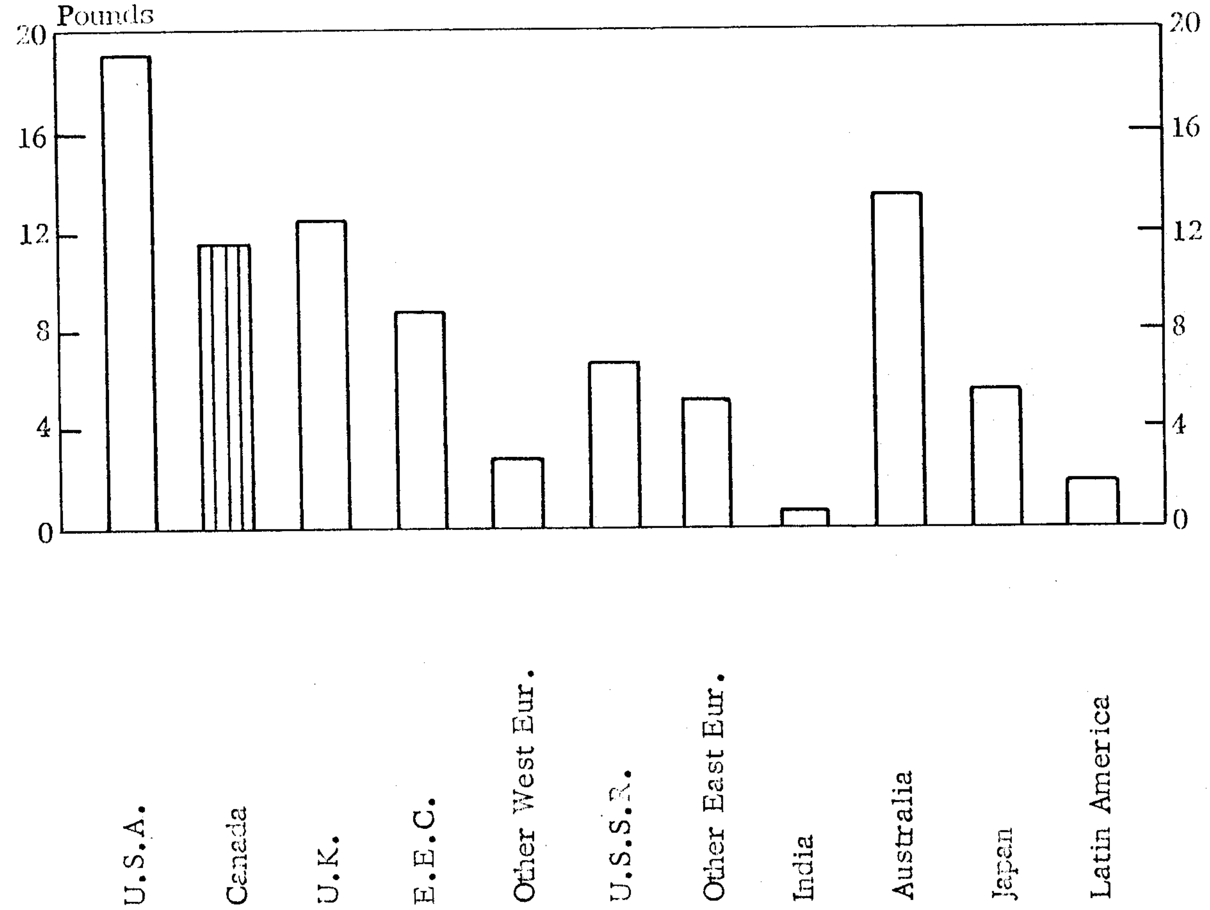
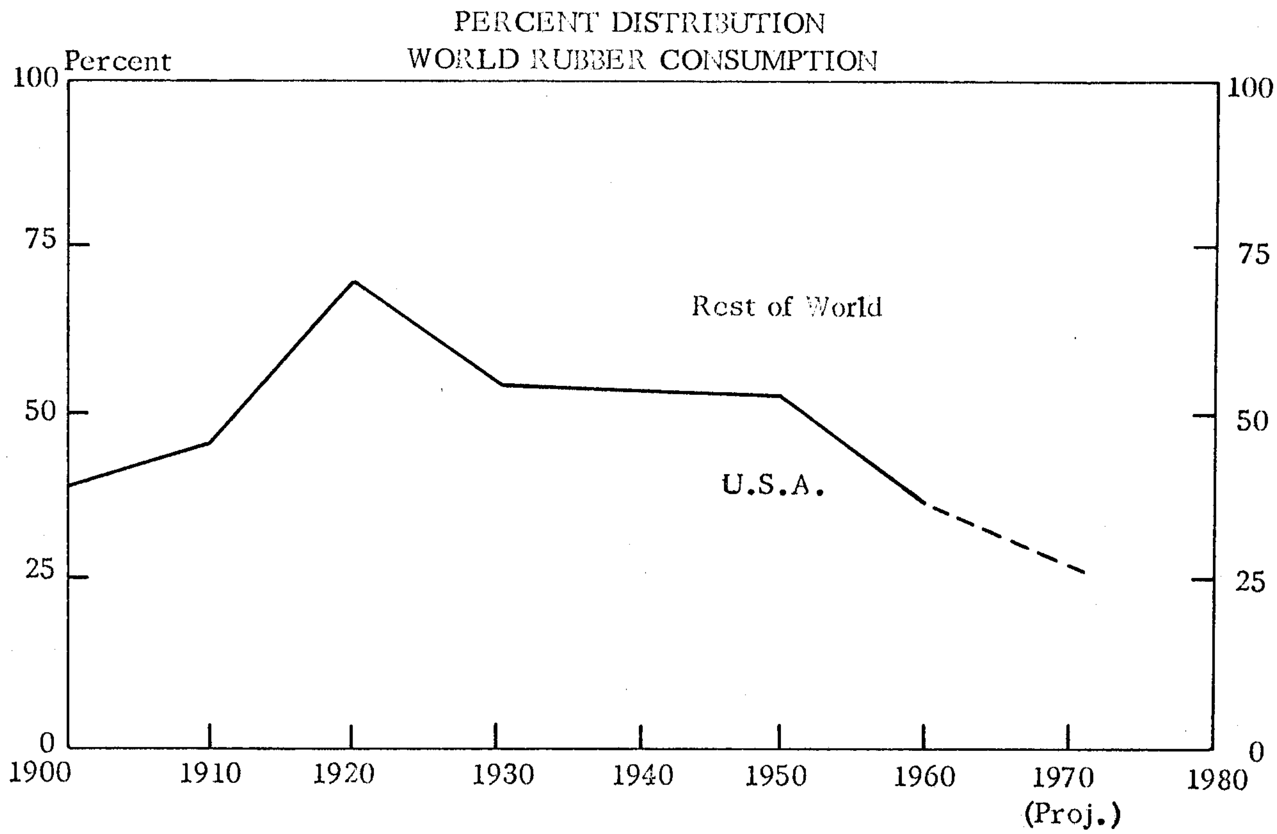


Figure 2

climate and other factors make the U.S. figure of about 20 pounds per head unattainable in many areas, but it is signigicant that even a narrowing in the disparity, certain to occur over the next ten to twenty years, means new demands for rubber measured in the hundreds of thousands of tons.

It should be noted that the current rate of consumption in the U.S.S.R. and other East European countries is fairly difficult to establish accurately, but a per capita use on the order of only five to seven pounds is believed to be of the right magnitude. Also, rubber use in China on a per capita basis is undoubtedly very small at the moment. Considering the rate of progression already demonstrated in these economies over the past decade and recognizing the planning goals they have set, we should anticipate that rubber consumption in these areas will occupy a steadily increasing share of the world's total use. Moreover, the significance should not be lost of the attempts of these economies to match their growing synthetic rubber needs with indigenous production.

The shifts that have taken place and which are anticipated in future in the regional concentration of rubber consumption may be summarized as in Figure 3. Until the decade of the 'fifties, from half to two-thirds of the world's rubber consumption centered in the U.S.A. By 1960 the U.S. share had dropped to just over one-third, and by 1970 a



PERCENT DISTRIBUTION
WORLD RUBBER CONSUMPTION

Figure 3

further decline to less than 30 percent is projected. As will be noted later, the regional shifts in rubber use are also finding expression in a change in the regional location of the burgeoning synthetic rubber industry.

A rubber market profile is incomplete without some reference to end-use. Across the Western World, a little better than 60 percent of all rubber consumed ends up in tires and related products such as tubes, retreads and repair materials. A multitude of other rubber products make up the balance, including footwear and solings, wire and cable insulations, hose and belting, technical articles, a host of other mechanical goods and latex products. Of the better than 2 million tons of new rubber employed in the tire group last year in the Western World, about 40 percent is estimated to have been used in passenger car tires where, technically speaking, a very high percentage of general purpose styrene-butadiene synthetic rubber can be used and is in fact preferred and being used. A large portion of the remainder of the rubber used in the tire segment finds its way into the heavier types such as truck and bus tires and into the retreading compounds associated with them. It is this latter field of heavy duty tires where the resiliency and certain other properties of natural rubber have given to natural the dominant position it enjoys today. Natural's dominance here is being challenged, however, by newer synthetic types. Recognizing the large tonnages involved and the fact that the resilient rubber market is the last major stronghold of traditional preference for natural rubber, the stage is set for an intensely competitive struggle in the 'sixties.

In accepting the challenge, the natural rubber industry has done and is doing much to establish a cost basis to ensure profitability at low prices. Productivity yields of three to four times past experience are now possible in the natural rubber growing areas, and the effectiveness of this in reducing the average cost of tree rubber will be felt more and more during coming years.

Technological Changes

In generalizing on significant technical developments in rubber, the tendency could be an over-emphasis on the struggles taking place between one type of elastomer and another. In fact, however, rubber in its many forms with varying properties is itself under constant pressure from threatened substitution by other materials much in the same way as rubber has itself substituted for other materials and developed new applications.

One of the distinguishing characteristics of the synthetic varieties is the wide range of types and grade sub-classifications produced, each tailor-made for one or several applications. This expansion through technical achievement to a versatile range of polymers has unquestionably enhanced the market opportunities for synthetic rubber, but it has placed rubber in many cases in competition with other materials, chief among which are the plastics. The dividing line between the two in terms of their functional purposes is becoming increasingly obscure in many applications.

Typical of these applications are the foam cushioning field where urethane polyethers are currently in direct competition with rubber latex; the flexible pipe and tubing field in which polyethylene and PVC have made impressive inroads against rubber; the footwear field where plastic soling is receiving increased attention as a competitor for both rubber and leather; floor tile where vinyl has already taken over a major share of the market from rubber. In the competition between rubber and plastics for these and other applications, the expenditure of a stream of research and development funds becomes a necessary requisite to ensure that rubber polymers obtain a fair share of many industries' raw material needs.

Within the rubber polymer field itself, technical discovery and innovation have radically changed the composition of rubber consumption according to source and type. This is seen in Figure 4 which describes the percentage make-up of the Western World's consumption of rubber, according to type of polymer, over the past twenty years. From a position of virtually 100 percent natural rubber prior to World War II we have moved to a situation where today less than one-half is natural rubber and over 40 percent is styrene-butadiene synthetic rubber. Chloroprene rubber and butyl rubber each represent just under 4 percent of the total with lesser amounts for oil-resistant nitrile rubber and other highly specialized rubber materials. Each type of rubber, whether it be from natural or synthetic sources, possesses some property or combination or properties required in end-products, and the foregoing division of the rubber market has developed.

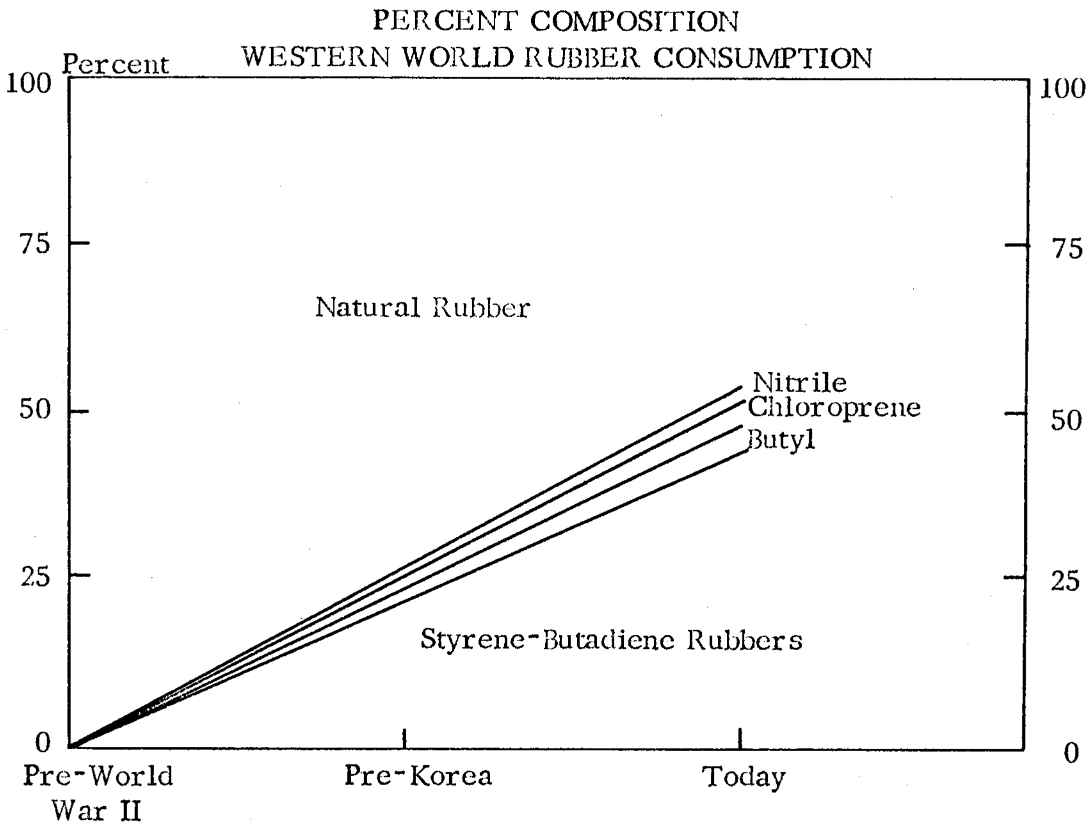


Figure 4

Exciting as changes over the past twenty years have been, the rubber polymer industry has very recently entered an even more remarkable era. This refers to the much-publicized technical break-through which now permits the synthetic rubber industry to perform the controlled synthesis of the rubber molecule in an ordered structure. The products of the new techniques, the stereo-regular rubbers, have properties which make them a direct replacement for tree rubber. Indeed, one family of stereo rubbers, cis-polybutadiene, demonstrates properties superior to natural rubber in many respects. The time is perhaps not too far off when it will be possible to use certain of these new rubbers as a 100 percent replacement of natural rubber in the major application of heavy duty tires, although in the present development stages the practice is to retain a proportion of natural rubber by blending with the new synthetics.

The break-through that has made available the production of stereo-regular rubbers has important commercial implications for the future. It is virtually certain that had the break-through not occurred the period of the 1960's would have been marked by a shortage of tree rubber, a very high price for the natural product and a consequent strong further stimulus to the building of general purpose styrene-butadiene rubber plants. As it is developing, however, the planning of stereo-rubber facilities in North America and many other parts of the Western World promises to add as much as 500,000 tons of capacity to augment the supply of natural rubber. On top of this, there is an accent in East Europe as well on the development of stereo-rubber facilities. Add to all this some expected increase in the availability of tree rubber itself and the prospect has changed to one, not of shortage, but of a developing surplus of resilient rubbers.

The commercial implications of these developments are far-reaching, because the struggle for the resilient rubber market to be waged between natural and synthetic sources of supply will have repercussions on demand and price down through the whole range of rubber polymers. It is inevitable, then, that the full attention of synthetic rubber producers will be given not only to the building of capacity to meet future rubber demand but also to the necessity of lowering production costs of both existing and new rubber types through increased efficiency and the maximum use of the most economic sources of raw materials.

Harnessing Resources for Rubber

In the past three or four years, both private and government-sponsored enterprise has invested heavily in new facilities to meet the increasing requirements of synthetic rubber. In this short space of time, the capacity of the Western World to produce synthetic rubber has more than doubled. Today in the Western World alone, excluding therefore the capacity of East Europe and China, the installed plant for producing synthetic rubber now exceeds the capacity of the natural rubber industry.

Between now and the mid-1960's there is under construction or planned additional synthetic capacity, in the Western World alone, to the extent of one million tons over the capacity in place in 1961, representing a 40 percent increase. A dramatic expansion is also taking place in the capacity to produce man-made rubbers in East Europe and China. An intelligent guess is that over the next five years as much as a doubling in the available capacity in East Europe and China will take place. At the same time, the production capability of the natural rubber industry is expected to increase moderately as the benefits from the planting of higher yielding trees and other efforts at yield stimulation bear fruit. The graph in Figure 5 brings into prominence the relationship between the existing and prospective capacity for the production of all types of rubbers in all areas of the world and the projected estimates of world demand.

It can be seen that for some period ahead the growth in world capacity will exceed the growth in demand. Undoubtedly, some slackening in the rate of adding new capacity must eventually take place, but it is of interest to note that the capacity already scheduled to be in place by the middle 'sixties will be capable of meeting the world's requirements of rubbers as far ahead as 1970. This is further evidence that the 1960's will be a serious testing period for all suppliers of rubber and that competition will be severe not only between various types of rubbers but also between the many suppliers of rubber as they compete in the market place on the basis of price, quality and service.

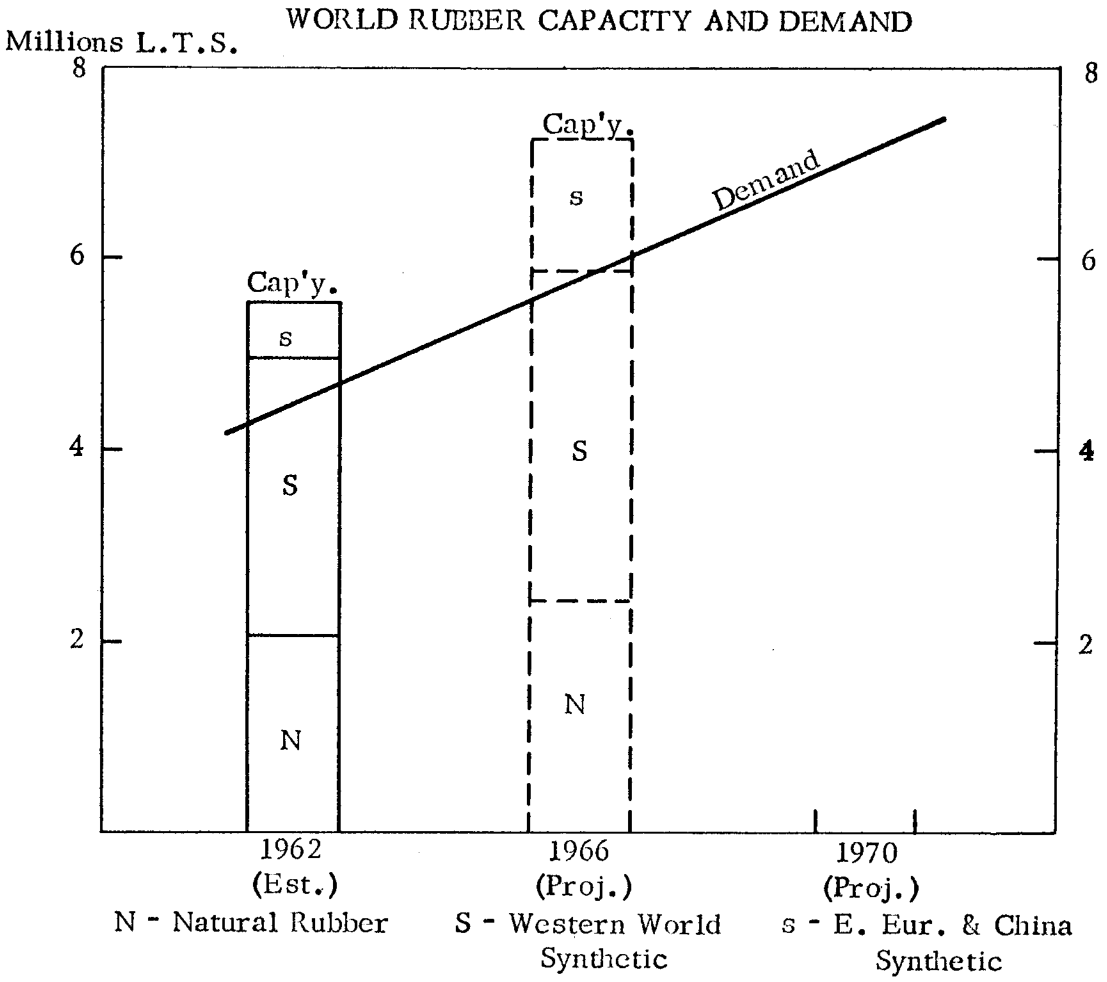

WORLD RUBBER CAPACITY AND DEMAND
Millions L.T.S.
8
6
4
2
8
6
4
2
Cap'y.
s
S
N
Cap'y.
s
S
N
Demand
1962
(Est.)
1966
(Proj.)
1970
(Proj.)
N - Natural Rubber
S - Western World Synthetic
s - E. Eur. & China Synthetic

Figure 5

In this matter of harnessing resources for rubber, it is important to appreciate that regional shifts in the concentration of rubber consumption are being accompanied by similar shifts in the location of synthetic rubber capacity. This is evident in Figure 6.

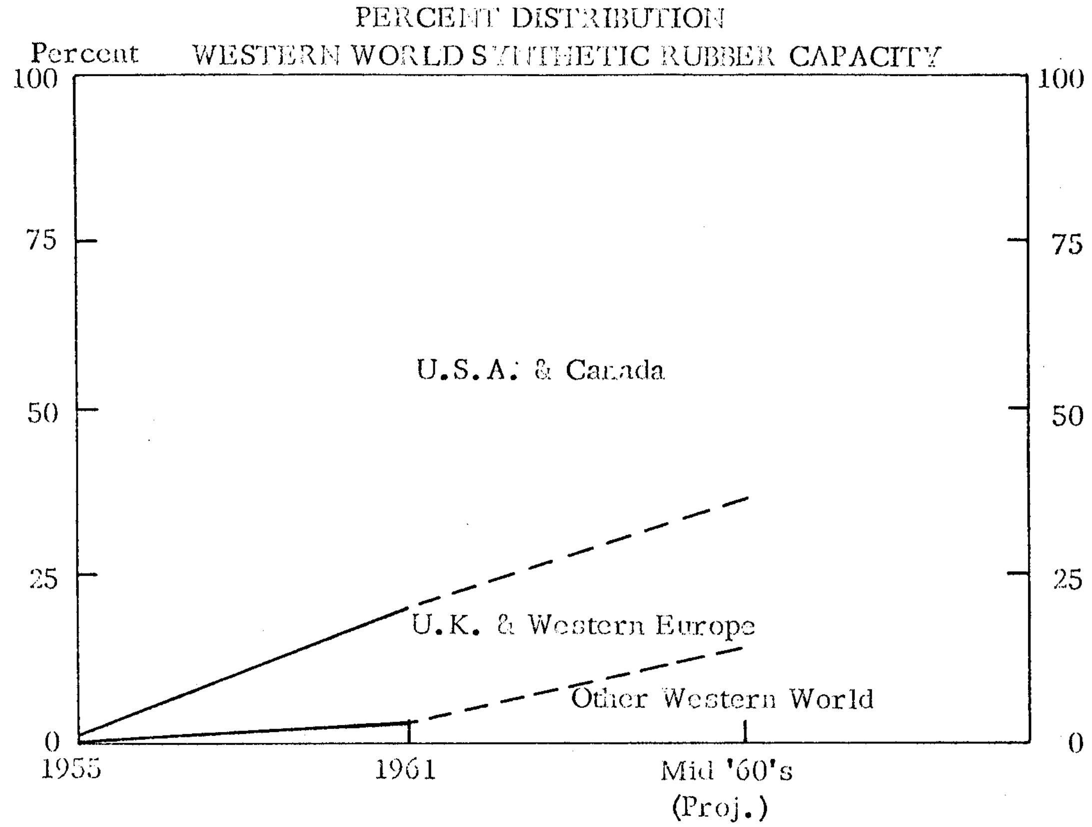


Figure 6

In the Western World in 1955, almost 90 percent of the synthetic rubber capacity was located in the U.S.A. with the balance in Canada and West Germany. By 1961 five additional countries had become major producers of synthetic rubber with the result that 17.5 percent of the installed capacity was located in Europe and 2.5 percent in Japan. In line with the continuing regional shifting in consumption it is indicated that by the middle of the present decade almost 23 percent of the capacity will be located in Europe, a little over 12 percent in other overseas areas, with the balance of 65 percent in the U.S.A. and Canada.

This trend to a decentralization in supply sources finds its origin in a number of factors. The primary one is undoubtedly the growth in the volume of synthetic rubber consumed in market after market to the point where the production locally for that market is of a size to be economically attractive. In more recent years, the doubling-up of markets through the formation of regional trading blocs has added encouragement to the construction of facilities based partly on hopes for export within the new trading areas. Furthermore, the post-war development of the energy resources of petroleum and gas to meet the growing demands for fuel in all parts of the world has coincidentally made available by-product supplies of hydrocarbons, the ingredients for the development of petrochemical industries. Indeed, in many countries national development policies to ensure full utilization of petroleum and natural gas have used as a starting point the development of a synthetic rubber industry as a major first step. In some countries too, special emphasis on the construction of synthetic rubber plants has been related not only to the availability of indigenous resources but also to the desire to conserve the foreign exchange which otherwise flows out in payment for rubber imports.

The new capacity for synthetic rubber in various parts of the world is being erected under conditions both of protection and non-protection, the exact degree depending on historical and other circumstances. Basically, however, it is characteristic of almost every synthetic rubber facility built to date to be an exporter as well as a supplier purely to its domestic market. In addition to this, the very diversity of rubber as between types and grades necessary to fill market needs strengthens the development of the industry on the basis of widespread exchange; national self-sufficiency in every type of synthetic rubber is neither economic nor practical. The fact, then, that the synthetic rubber industry so far is being planned on this basis of a reasonable degree of international exchange is a hopeful sign to suppliers who have, for a long time, prospered on the basis of selling to the world market on a freely competitive basis.

To put the matter in its most objective terms, we might state that for the healthy development of the rubber polymer industry there must be a continuation of free movement of supply between trading nations. Certainly the company I represent firmly supports free trade in rubber as the desirable ultimate goal in this respect.

In light of the trends taking place in the structure of the synthetic rubber industry and its markets, suppliers have to recognize a number of factors in their plans to profit from the future growth in rubber demand.

The first factor to be recognized is that shifts are taking place in the location of synthetic rubber capacity toward the areas of fastest growth in consumption. This capacity sometimes has the benefit of tariffs and other forms of protection but there are many examples of new facilities in which the investment has been made on grounds of straight commercial advantage without the benefits of protection.

The second factor has wide application in industry generally but is particularly important in the case of the complex elastomer field. This is the emphasis which must be placed on marketing strength and ability through maximum attention to product quality, price, deliveries and technical service to the customer. In the new era of regional groupings of large consumer areas, marketing strategies require that the closest attention be given to the most desirable location of plant facilities.

Finally, the competitive struggle which has already begun in the rubber market and which promises to intensify in this decade makes low cost of product a requisite to survival. As never before, existing suppliers as well as new entrants into the field will be looking for the lowest possible combination of cost elements involving raw materials, energy, manpower, freight and capital.

DISCUSSION

Dr. J. A. McCoubrey, Cyanamid of Canada, Montreal, Quebec: In the first slide I noticed that Australia ranked as a large consumer of rubber. The high Australian consumption was very striking. Perhaps you could elucidate why Australia would have such a high per capita use of rubber?

Mr. R. C. Sykes, Polymer Corporation Ltd., Sarnia, Ontario: I think it is related to the fact that most of the population is spread along the strip of Australia and 80% of their rubber is used in transportation which would confirm that it is related to the car. They have an excellent railway system and I would judge that most of that transportation rubber, or a good portion of it, would be for passenger use. They have a high car population per head.

Mr. R. G. Nicholls, Pan American Petroleum Corporation, Calgary, Alberta: I was wondering, Mr. Sykes, if you could tell us just where the synthetic rubber plants in Canada are presently located.

Mr. R. C. Sykes: There is just the one, the Sarnia Plant. In addition, Dow does produce a rubber latex paint. I think we should mention that it is also a rubber plant of some significance.

Mr. D. H. F. Black, Department of Industry, Government of Saskatchewan, Regina, Saskatchewan: I would like to ask Mr. Sykes what the probabilities of a branch plant are in Western Canada and whether the products line, economics of the products line, tend to produce this possibility.

Mr. R. C. Sykes: I am not intimately connected with the negotiations that have been carried on. You are aware there has been extensive investigation of the Alberta area by Polymer. I am only able to say that nothing has been decided one way or another. It is one of these shelf projects. Alberta continues to be a place where you have to look at the economics in comparison with the economics elsewhere. I would not be familiar with the effect of a products pipeline nor how the economics of some new venture might affect this.

TRENDS IN PLASTICS

G. D. Garrett, Jr.
Union Carbide Canada Ltd., Chemical & Plastics Division, Toronto, Ontario

Mr. Garrett graduated with the Bachelor of Arts degree from Dartmouth College. After graduation he joined the Union Carbide fellowship at the Mellon Institute of Industrial Research in Pittsburgh, Pennsylvania. He has been associated with Union Carbide continuously for 30 years. Most of this time has been spent in various marketing aspects of the Chemicals and Plastics interests of Union Carbide. He came to Canada in 1946 to organize a direct sales effort for the Chemicals Division of Union Carbide Corporation. He is currently employed at the Head Office of Union Carbide Canada Limited in Toronto.

Webster defines trend as "to have or to take a particular direction". Happily for me, he gives us a second definition, "underlying or prevailing inclination".

The short history of the plastics of commerce demonstrates the futility of attempting to find a "particular direction" for their future. Hence the best we can do is to make an intelligent speculation based on our present-day knowledge of plastics.

A plastic is a material that contains as an essential ingredient an organic substance of large molecular weight, is solid in its finished state, and at some stage in its manufacture or in its processing into finished articles, can be shaped by flow. The term is also used sometimes to include inorganic materials of similar character. Having defined the title - trends in plastics - let us now consider the general field.

Today there are 19 major families of plastic resins and compounds, ranging from celluloid and phenol formaldehyde - the forefathers of the industry - to styrenes, vinyls, polyesters, epoxies, polyethylene and even newer polycarbonates and polyformaldehydes.

In every walk of life, in every phase of industry, plastics are playing an increasingly important role. They are an integral part of our economy - grinding wheels bonded with phenolic resin --- printing plates for the latest editions of the Bible --- toys that don't break --- bonding material for solid fuel rockets --- styrene cable spaces for electric high tension lines --- automobile and furniture upholstery --- metal coating as flexible as the metal itself --- high strength plastic pipe.

Probably most of us arrived at this symposium today in an automobile. In 1956 there were 15 1/4 pounds of plastic used in the average car. In 1962, this figure is 30 to 35 pounds, depending on the make and model. The use of plastics in automobiles is not something new, for phenolic resins are what made brake linings possible over 40 years ago, and also enabled Charles Kettering to develop the distributor for the ignition system.

The rapid progress of plastics is not just happenstance - it has come about because of the dynamic character of the industry. It is a highly specialized field of organic chemistry. As such, plastics producers must conduct vigorous and intensive research in many fields. They must be skilled not only in the production of their own materials, but in the development of end-use applications. Each year, capital expenditures by the industry for increasing production capacity run into hundreds of millions of dollars.

Plastics are becoming so plentiful in their various applications that today they are counted among the major industrial raw materials. In North America they now exceed the major nonferrous metals for tonnage used. Also, since plastics are far lighter than metals, their consumption already exceeds that of aluminum in physical bulk. For a class of commodities of which all but a few were practically unknown a few years ago, this is a truly remarkable record.

Few of us here would argue with the economists who tell us that we are living in the age of steel. This metal has been the foundation of our economic society for many years. It is the skeleton around which we construct our buildings, and it is the road on which we transport our goods. Without steel our urban society would not have been possible.

A comparison of plastics with steel is enlightening. In 1959 Canada consumed 5848 tons of steel and 320 million pounds of plastics - a mere 2.7%. However, if we convert our pounds to cubic feet plastics become a respectable 14% of steel usage. If we go one step further we find that the steel ingots had a value of $18,000,000, while the primary plastics brought $103,000,000.

The many uses and possible applications of plastics are not surprising when one considers the wide range of physical qualities which they possess. They may be translucent, opaque or transparent. Some are rigid; some are flexible; while others have elastic qualities. There are plastics to satisfy various strength requirements - tensile, flexural, impact or pressure - depending only on the proper choice of materials. There are plastics which are particularly resistant to moisture, corrosion and moderate heat. Others are good insulators.

These differing physical characteristics do not altogether explain the adaptability of the plastics. They may be formed into almost any desired shape. Some plastics may be molded or cast --- such as telephone hand sets and radio cabinets. Sheets can be formed into airplane cockpit enclosures or instrument panel faces. In the form of film, plastics can be used for packaging or display purposes, upholstery or wearing apparel. The production of any laminated objects, including safety glass and metal aircraft panels, are made possible through the use of plastic bonded resins. Tables and kitchen and bathroom wall panels are further examples. They may be used to coat or impregnate other materials, appearing as refrigerator and automobile enamels, seat coverings, etc. As adhesives or bonding agents, plastics are already being consumed in large quantities by Canada's plywood industry. In another form they appear as fibres fine enough for the sheerest hosiery, and coarse enough to replace wire window screening.

Obviously, no one material can have all the qualities necessary to fill all these roles. But the plastics are not one, but many. They are a family group, and a very versatile family too.

Let us now consider those products which are of major commercial significance today and those which promise to become so in the immediate future. This is hazardous. For instance, I consider such products as the silicones and fluorinated polyolefins to be specialties because of the very high cost of production. Yet a significant breakthrough in processing could send these products into the astronomical tonnages of polyethylene and the vinyls. Such a breakthrough has recently been made in the foamed form of polyurethane plastics. Polyesterurethane foams exhibit many interesting characteristics, but the flexible foams could not compete with foamed rubber and the rigid foams could not compete with foamed styrene. The development of polyether-urethanes have lowered costs to a point where they can compete with the established products.

Let us consider the work horse plastics - polyethylene, vinyls, polystyrene, phenolics, epoxies and one of the new members of the family, polypropylene.

These major plastics are becoming firmly established as staple commodities. In that role, their future is assured in a constantly increasing number of applications in good times --- and in bad.

Polyethylene, the biggest in plastics, got bigger by another 20 percent in 1961. In Canada last year, production capacity was about 135 million pounds and by 1963, producers predict that this will reach 180 million pounds. In the United States production capacity in 1963 is predicted at over two and one-half billion pounds.

Although it has been suggested in some quarters that a plateau has been reached in low density polyethylene consumption, this scarcely seems likely in view of the number of markets where polyethylene is still in the early stages of use. The field of automatic over-wrapping is an example. Practically non-existent two years ago, this technique is making rapid strides into new market areas and should provide larger outlets for polyethylene for years to come.

An indication of the growth in this application is the fact that in 1960 there were 250,000 pounds of film sold to Canada's baking industry. In 1961 this poundage mushroomed to over two million pounds. Polyethylene film manufacturers are now predicting that in 1962 this figure will reach the four million pound mark. About 75 percent of Canada's major bakeries have changed or converted their over-wrapping machines for actual or possible use of polyethylene film.

Another good and far from saturated market is the packaging of fresh produce. A number of good chains are now requesting that their produce be prepackaged before it reaches the stores. Affording superior protection --- increasing sales appeal --- and providing faster checkouts in this streamlined business --- polyethylene film can and is, filling a real need.

Continued progress has been made in the development of new compounds with improved fabricating or use characteristics for specific applications. One major breakthrough was the development of a crack-resistant polyethylene material to meet the stringent requirements for submarine cable applications.

After several years of extensive effort directed at the development of high density polyethylene compounds, major markets have begun to appear for this material. Foremost has been the detergent bottle. Areas in which consumption is still low, but future requirements large, include the automotive field where both blow-molded and thermoformed components of high density material offer great promise.

Vinyl resin consumption in Canada increased 16 percent in 1961 with a total of 49 1/2 million pounds. In the United States, over 250 million pounds were produced in 1961.

Despite increased usage, an overbuilt situation still exists in the polyvinyl chloride industry. Conditions are further aggravated by imports, particularly in film and sheeting, and manufacturers saw these rise to a level about one-half of their home production.

Vinyls continue to increase in a number of areas. Coatings - both solution and dispersion types --- find growing markets. Acceptance by contractors and home buyers of vinyl-coated aluminum siding is just around the corner.

The Aluminum Company of Canada is erecting model homes in Montreal, Toronto, Winnipeg and Vancouver. These homes cannot be considered experimental since the materials used are fully approved, and were adopted only when they showed economies over the conventional materials they replaced. The baked-on vinyl coating should obviate the necessity to paint a house unless the home owner wants to change the colour. Much of the future growth of vinyl will be attributable to greater penetration of the building field. Already widely used for flooring, luminous ceilings, water stops, and both exterior and interior coatings, vinyls are steadily taking over a greater share of these markets as well as beginning to find use in other functional elements of buildings.

Polystyrene consumption in Canada increased by five percent in 1961 to 22 million pounds. Production for the year topped 43 1/2 million pounds, indicating a present dependence on export markets.

Among the important product developments in this plastic has been a new extra-high impact material produced both in regular and self-extinguishing forms. Maintaining very high strength over a wide temperature range, and with low moisture absorption and good resistance to distortion, the new material is rapidly carving out markets in the appliance and other fields. Housings made of this material for appliances, room air-conditioners and motors are durable, warp-free, and offer increased safety because of the fire resistant characteristics.

Another development is the new medium impact material displaying unique properties when molded in thin sections. Because of the extremely low orientation developed during molding, this material has great strength even at sub-freezing temperatures. This application has found extensive use in the frozen food field.

The use of bi-oriented sheeting is increasing rapidly in the transparent packaging field. Development work is proceeding in our laboratories on the blow-molding of polystyrene and its copolymers. While blow-molding is largely a polyethylene technique, it holds promise for all the thermoplastics. One pound of polystyrene provides rigidity equal to that given by 1.4 pounds of polyethylene, and cost per pound is lower.

The coffee break has become as firmly established in North America as afternoon tea in Britain. The new disposable styrene cups are an improvement over the paper cups of yesterday.

Because of the increased demand for plywood resins, phenolics gained slightly in 1961, compared to a decline the previous year. 1961 production was 46 million pounds.

Despite the poor short-term prospects for phenolics, we have complete confidence that they will long remain the resin "too good to be outmoded". A breakthrough in the development of phenolics with greater heat resistance has been one of the major accomplishments. These new materials withstand four times longer exposure at 500°F. than the best previously available phenolics. Important applications are foreseen in the appliance, automotive,missile and other fields where high temperature durability is required.

Phenolics have in the past found use in the production of wood panels, plywood, chipboard, wood waste composition board, etc., but their growth has been limited by their relatively high price compared with that of urea bonding materials. The increasingly apparent need for better properties, particularly water-resistance has drawn serious attention to the broader application of phenolics in this area. Pre-fabricated panel construction, a fast-growing technique urgently needed to maintain reasonable costs in domestic housing, requires bonding materials with high strength and moisture-resistance. Phenolics provide a thoroughly satisfactory solution to this problem.

Epoxy resin sales and production in Canada increased 10 percent in 1961. Production was over one and one-half million pounds. In the United States, it topped 60 million pounds.

While a few major new uses have appeared for this relatively young member of the plastics family, it is becoming solidly entrenched in a variety of fields because of properties offered by no other material.

The inherently high cost of epoxies compared with most other resins has been somewhat of a hurdle. As factors of quality and service life receive more attention, it appears that long range economies can be achieved with this resin in large scale applications where cost must be a matter for careful consideration.

One such instance is the surfacing and repair of highways. Viewed with caution by highway authorities - when first proposed - because of materials and application costs, the demonstrated performance of epoxies in test sections of highways surfaced several years ago has led to a change of opinion. A Canadian company has now developed a machine for injecting epoxies into cracks in roads and bridges.

Of course, the most outstanding property of epoxies, their adhesiveness, is still creating a high acceptability for brake linings, aircraft parts and in repair kits.

One of the newer members of the polyolefin family - polypropylene is just coming into its own in Canada. Last year, nearly one-half million pounds of this plastic was consumed. In the United States, 70 million pounds of this product was consumed, double that of 1960.

The largest portion of polypropylene went into moldings - having been used in the production of luggage cases, TV backs and chairs. Monofilament for rope, woven upholstery, web, etc., made from polypropylene are now on the consumer market. Because of its light weight and weatherability, manufacturers expect that polypropylene will eventually become the dominant factor in the cordage industry.

Polypropylene film of course, has the greatest interest. Most intensively developed uses for polypropylene are in shrink films for phonograph record albums and multi-unit bundling, but it may become practical for all sorts of flat wrappings.

Statistically in 1961, Canada used over 360 million pounds of plastics - or approximately 20 pounds per capita. This consumption was up nine percent over the previous year. In the United States 6.3 billion pounds were consumed, equal to 35 pounds per capita.

Polyolefin capacities for 1962 in some of the free countries of the world include 223 million pounds in France; 385 million pounds in Italy; 465 million pounds in Japan; 315 million pounds in West Germany and 450 million pounds in the United Kingdom. Puerto Rico predicts that by 1965 it will be producing 110 million pounds of polyethylene and polypropylene.

Throughout the Free World the consumption of plastics has been increasing steadily. In 1959, 11.6 billion pounds were used. In 1960, this increased to 13.1 billion pounds and in 1961 a record 15.1 billion pounds were consumed.

This phenomenal acceptance of a product family which has only been in existence for 75 years is also revealed in the consumption statistics for Canada and the United States. In 1959, Canadians consumed 320 million pounds compared to 5.6 billion pounds in the United States in the same year. In 1960 Canadians consumed 330 million pounds and in 1961, 360 million pounds. In the same years in the United States, they consumed 5.5 billion pounds and 6.32 billion pounds respectively.

The Canadian growth rate for 1961 was 9% while in the United States it was 13.6%, and in the Free World, 15%.

The plastics industry is so closely allied with the chemical industry generally that we might look at the over-all contribution of the industry to the Canadian economy. Today, there are 1,145 chemicals plants in Canada which employ an estimated 56,000 persons. More specifically, in the Canadian plastics industry in 1961, there were 280 primary and secondary plants employing 11,200 people. Total sales in the plastics industry was over 234 million dollars.

Since 1948, approximately one billion dollars has been invested by the Canadian chemical industry in new or expanded production facilities. In 1959, materials for use in chemical manufacturing cost 624 million dollars and fuel and electricity approximately 50 million dollars. Employees of the chemical industry were paid over 240 million dollars in wages.

I mentioned that there were 1,145 chemical plants in Canada today. In 1920 there were 451. The figure of 56,000 employees is nearly four times as many as 1920's work force of 16,000.

The economists tell us that the Canadian chemical industry will grow at a compound rate of 7% in the next 20 years. In 1959 the entire chemical complex showed a growth of 6.4%. Compare these growth rates with that of all Canadian industrial production, which has a predicted growth rate of 5%, while the total economy of Canada is only growing at 3 1/2%.

The ubiquitous nature of plastics prompts the observation that here is an instance where man's ingenuity is limited by his imagination.

Few of us are not fully aware of the tremendous extent to which plastics have entered our lives. Suppose that plastics suddenly ceased to exist. This room would be plunged into darkness. All power transmission would cease; no electrical communications medium would be operative; no car, bus or train would run and no plane would fly. Thousands of children would be sitting empty-handed in playrooms that a moment ago were full of toys.

No missile would leave its launching pad, no car would have a coat of paint, the supermarket manager would be standing up to his knees in loose potatoes and up to his armpits in detergent suds. There would be huge solid mounds of candy, and the biggest mixed fruit and vegetable salad you ever saw. To get into a drugstore, you would have to wade through the loose toothbrushes. It would smell like all the barber shops in the world rolled into one. The neighborhood liquor store would have row upon row of bottles with no caps on them.

To this picture of an industry with unlimited horizons, I would like to briefly add some of the more somber hues of investment. If I were considering investing money in a plastics plant in Alberta today, I would ask myself the following questions:

Is this a new product in which esoteric knowledge or patent rights will permit me an exclusive position in the market place for a reasonable period of time? If so, I would be inclined to take my risk on the basis of my market researchers.

If the product is mature, as the phenolics, or reaching maturity as are the vinyls and polyethylene, I would carefully examine the people already in the business to see where I would fit in. There is an extremely high overhead in the mature plastics, especially in the area of research and development. I would avoid the pitfall of thinking I could compete by avoiding this expense, and putting up a plant simply to "make and sell". Although the basic forms of mature plastics are well established, there is continuing severe competition in product variation to meet new market demands. Hence, product development is as much a part of your cost as raw materials.

What are world trading conditions on my plastic? I would want the hard facts of tariffs, uncomplicated by the starry-eyed possibilities of free-trade. The situation on polyethylene provides a good case study. This resin is protected in Canada with an ad valorem rate of 7 1/2%. In the United States their combined rate of 3.4¢ per pound plus 25 1/2% is the equivalent of about 38% at today's prices. On July 1st, 1961 Japan increased their tariff from 20% to a specific rate equivalent to 30%. Common Market rates range from 20% to 23%. United Kingdom manufacturers have recently petitioned the Board of Trade to increase the duty from 10% to 33 1/3%. Under these circumstances the foreign producer can pay Canada's 7 1/2% and sell his surplus production in my market at a profit. I would have to curtail production rather than try to leap over the high tariff walls in other industrialized countries.

This leads to another question. What are the real export opportunities for my plastic? A new plastic should find ready acceptance at a profit not only at home, but abroad. A mature plastic is likely to run into domestic production in any country that has developed enough to use it. Union Carbide alone has erected polyethylene plants outside of the United States and Canada in the following countries: Australia, Belgium, Brazil, Italy, India, Japan, Great Britain, and Sweden.

I would then ask myself this question: What is the possibility of Canada developing the type of co-operation between labour, management and government which has enabled the war-ravaged countries of Germany, Italy and Japan to dramatically reconstruct their industrial economies?

With the right answers to these questions I would invest in my Alberta plastics plant with some confidence. Without them I would be inclined to keep my money under my pillow.

If what I have just said sounds pessimistic, I meant it to be so. However I do believe in the future of the plastics industry. I hope that Canada can continue to participate in its growth. If it does, Alberta which offers so much to the industry is sure to be the scene of substantial investment.

Sixty-six years ago Peter Townsend Austen penned a statement on the importance of chemistry. Some of you may be familiar with it:

> "It is fair to hold that the country that has the best chemists will in the long run be the most propserous and the most powerful. It will have at the lowest cost the best food, the best manufactured materials, the fewest wastes and unutilized forms of matter, the best guns, and the strongest explosives, the most resistant armour. Its inhabitants will make the best use of their country's resources; they will be the most healthy, and the most free from disease; they will oppose the least resistance to favourable evolution; they will be the most thrifty and the least dependent on other nations. The education of its people in chemistry and the physical sciences is the most paying investment that a country can make".

This statement has proven true 66 years later, and had it been written today, I am sure it would prove to be equally true 66 years hence. And as for chemistry --- so for plastics --- the future of this segment of the chemical industry is indeed rosy. Based on the statistical trends in plastics, I sincerely believe that the promise for the future will far exceed the accomplishments of the past.

DISCUSSION

Mr. K.W. Soles, Van Waters & Rogers, Edmonton Alberta: I remember some years ago, a newsreel shot of Henry Ford taking an axe to a trunk of a car that he developed in some type of plastic. Do you think that in the next two decades an invasion of the plastic industry into the cars would raise that level of 35 pounds per automobile to something around 30% of its total weight.

Mr. G. D. Garrett, Union Carbide Canada Ltd., Toronto, Ontario: Being an optimist, I do foresee it. As you know, the Corvette, the sportscar of G.M. has had a plastic body. I am not too familiar with all of the problems they have encountered with broken fenders. I understand that there are repair kits which enable you to do a good, quick repair.

TRENDS IN AGRICULTURAL CHEMICALS

G. W. Selleck

Plant Ecologist, Development Department, Monsanto Chemical Company, St. Louis, Missouri

Dr. Selleck, born in Saskatchewan, received his secondary education in Spalding, Saskatchewan, and attended the Universities of Saskatchewan and Wisconsin receiving the degrees of B.S.A., 1950, M.Sc., 1953 and Ph.D., 1959. He served on the staffs of both universities and then in 1960 joined Monsanto Chemical Company as Plant Ecologist and senior Project Manager, Agricultural Chemicals Development.

The trend in agricultural chemicals is unmistakable. The value of chemicals in increasing farm production at lower cost has been recognized and sales are on the upswing. Sales of agricultural pesticides in the United States have increased nearly 100% from $161,000,000 in 1953, and have increased annually for 8 consecutive years reaching a total of $363,000,000 at the manufacturer's level, an all time record for the industry. Similar trends occurred in Canada. Sales of pesticides in Canada surpassed $28,000,000 in 1960 representing an increase of almost 7% since 1959. These increases in the use of agricultural chemicals occurred despite accumulated surpluses of foodstuffs and retirement of thousands of acres of rich farmland from production in the U.S. These trends are not confined to North America. The production of pesticides in Japan increased from $76,500,000 in 1959 to $93,500,000 in 1960. The use of agricultural chemicals has been increasing in Britain in recent years, reaching a value of approximately $87,000,000 in 1961. Further increases are expected when Britain joins the European Common Market.

Universities and land grant colleges have demonstrated that crop losses can be kept to a minimum by using a season long pesticide application program. There is, however, a lag in commercial acceptance since the annual losses caused by agricultural pests are estimated in excess of $13,000,000,000 in the U.S., nearly $1,000,000,000 in Canada, and approximately $150,000,000 in Britain.

Herbicides

Losses due to weeds have been estimated at $5,000,000,000 in the United States and $570,000,000 in Canada. The use of broadleaved and grassy weed killers have assisted materially in combating these losses.

Since its discovery 15 years ago, 2,4-D has become widely used for broadleaved weed control. Development was particularly rapid during 1947-1952. By 1952, herbicides were being applied to over 30,000,000 acres of cultivated land in the U.S., including 17,000,000 acres of small grains, 9,000,000 acres of corn and 5,000,000 acres of other crops. In western Canada, the use of 2,4-D expanded rapidly from 500,000 acres in 1947 to 13,500,000 acres in 1950 and remained at this general level until 1955. During the next 4 years, treated acreage approximated 16,000,000 acres annually. An all time high was reached in 1960 with 22,000,000 treated acres which decreased only to 19,000,000 acres in 1961, despite severe drought conditions. The fact that farmers are beginning to realize that improved weed control can be obtained more economically at rates of 6 to 8 oz. per acre instead of 3 to 4 oz. will increase sales volumes further. The present treated acreage represents approximately 50% of the total that should be treated. With the necessity for decreased production costs in agriculture, the use of herbicides should increase significantly in the future.

Numerous formulations of 2,4-D have developed, including salts, amines and esters in several concentrations, represented by 2,4 and 6 pound per gallon formulations. The more concentrated formulations of 2,4-D are becoming more popular, permitting maximum economy in its use. The introduction of low volatile esters and amines has decreased the hazard of injury to susceptible crops.

Since the introduction of 2,4-D, several herbicides have been developed for broadleaved and grassy weeds in crops. Substituted ureas and dalapon have made significant contributions to weed control. Randox*, Randox* T and Atrazine are examples of pre-emergence herbicides used in corn. Another important breakthrough was the development of the selective herbicides, Avadex* and Carbyne for wild oat control. In heavy wild oat infestations, a commercial application of Avadex in 1961 resulted in increased flax yields of 13 bushels per acre. This will significantly decrease crop production costs since the wild oat is the most severe weed pest in western Canada and the north central States.

There has been a distinct trend in recent years toward the increased use of granular formulations. These have developed particularly in corn and vegetable crops and enjoy widespread farmer acceptance. Two obvious advantages of granular formulations are ease of application and improved selectivity to crops. A disadvantage is the higher cost per acre.

A trend has developed toward mixing of herbicides to obtain a broader spectrum of weed kill. 2,4-D and dalapon have been mixed to control both grassy and broadleaved weeds in legumes or flax. Mixtures of IPC and Endothal have been used for broadleaved and grassy weed control in sugar beets. The mixture of Randox and Vegadex appears promising for both classes of weeds in potatoes, cole crops and celery. Other mixtures showing promise are Randox and IPC, Atrazine and Randox, and Randox and dinitros.

The scarcity of labor particularly in specialized crop areas, places effective herbicides in great demand. In New York State for example, labor costs may exceed $200 per acre to hand hoe onions, in contrast with chemical weed control costs of approximately $30 per acre.

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* Trademark of Monsanto Chemical Company, St. Louis, Missouri. Reg. U.S. Pat. Off.

Aerial applications of herbicides have become more popular in recent years. The acreage treated by air in the United States exceeded 50,000,000 acres in the period 1956-1959 compared with 38,000,000 in the previous 3-year period. Application by air is not uncommon in the Red River Valley and is the usual procedure for weed control in rice in the southern states.

Herbicides are being developed for an ever-increasing variety of crops. Rogue and Stam 34 have been developed for barnyard grass and broadleaved weed control in rice. Control of specific grasses, such as cheatgrass, wild rye grass and Johnson grass can be expected in the near future.

There is a marked trend for the development of herbicides tailor-made for control of a specific weed pest, particularly where a large market exists. The wild oat is a good example. Specific development for weed problems of a more local nature on high priced crops will occur as a matter of necessity since the large markets are rapidly disappearing. Products are available for broadleaved and grassy weeds in the Corn Belt but there is room for more effective chemicals particularly under some soil conditions. The market for herbicides is approaching the stage when it will be one of replacement as opposed to new uses.

Thousands of chemicals are screened each year and "data processing" is becoming more important to research and synthesis of agricultural chemicals. All data on new chemicals are carefully recorded and fed to a computer. For instance, if a test chemical "X" shows remarkable quality as a weed killer but lacks persistence in the soil, it is possible to ask the computer for previously tested chemicals which show persistence. The most promising molecular configuration responsible for persistence may be attached to chemical "X" to provide the desirable property. As more and more chemicals are tested, a varietal catalogue of properties becomes available to the computer. Such an approach will lead to chemicals specifically designed for a prevalent weed in a single crop.

Fungicides

Plant diseases cost farmers $3,000,000,000 annually in crop losses in the U.S. This is equivalent to retiring 30,000,000 acres from crop production.

The field of fungicides developed through the accidental discovery in France some 75 years ago that a mixture of lime and copper sulphate (Bordeaux mixture) controlled grape mildew. Shortly after the turn of the century, lime sulphur was developed for controlling apple scab. Until 1930 these two were the standard preparations for disease control.

In the 1930's the dithio-carbamates were developed for foliar diseases of vegetables and fruits. More recently, captan and dodine have become widely accepted for the control of apple scab.

The control of plant diseases through seed treatments has developed in grains since 1925 and expanded to approximately a $5,000,000 business annually.

Since 1955, research has concentrated on the field of soil fungicides, from which Vapam, Nebam and Zeneb have developed. Their use, however, as soil fungicides are relatively limited, being used primarily on foliage and fruit. Current sales of fungicides account for approximately 20% of the total pesticide volume.

The development of new fungicides will probably be directed to the control of seedling blights, wilts and root rots of field vegetables, fruit and ornamental crops, with emphasis on cotton, sugar beets and peanuts. Seven major soil-borne diseases include Pythium, Phytophthora, Rhizoctonia, Verticillium, Fusarium, Sclerotinia and Sclerotium. Of the soil fungicides, PCNB and Vapam have enjoyed appreciable success. Cotton, sugar beets, peanuts, tobacco, citrus, beans and other fruits and vegetables are classed as target crops because of their susceptibility to fungi and high return per acre.

Soil fumigation, especially in connection with higher priced crops, such as tobacco, is an area which will receive more attention.

There is likely to be a breakthrough in chemotheropeutants in the fungicide field. There are several diseases which affect the vascular systems of plants. A fungicide which is translocated by plants would be a logical method of approach. In fungicides, a longer residual effect would be beneficial to avoid re-application after every rain. This would also provide protection for new leaves.

Insecticides

Insects are reported to cause an estimated annual loss of $4,000,000,000 in the U.S. Sales of insecticides account for approximately 58% of the total value of pesticides used with cotton being the largest single potential. Fruits and nuts are the next largest potential to make up the total $145,000,000 production of insecticides at the manufacturers' level. Sales of insecticides increased approximately 7% during 1961 as a result of heavier than usual insect infestations during the past growing season. Since its first production in 1943, DDT sales have increased to 165,000,000 pounds per year in the U.S.

The insecticide market is a relatively mature one, since all insects of major importance can be controlled by available insecticides. The market for new products is therefore one of replacement as a result of the development of insect resistance or insecticides with cheaper application costs. The number of insects that are becoming resistant to insecticides continues to grow, but they can be controlled with one substitute insecticide or another.

The most disheartening aspect is that no clear and permanent solution is in sight. Reserves of new types of chemicals having different modes of action to counter resistance are limited and reserves of basic knowledge upon which to develop new types of chemicals seem to be inadequate. Although there is no cause for alarm in the immediate future, we cannot ignore the great impact that resistance to insect control chemicals will have on agriculture and public health in the years ahead. Most insect pests are combated by chemical means and there is every indication that chemicals will be emphasized for insect control for years to come.

Research on mode of action permits the development of compounds that will produce a desired biological activity. Attractants are being used to a greater extent. Insect attractants obtained from female gypsy moths are used to capture the males. The possibilities of developing chemicals based on the composition of sex attractants seem almost unlimited. The use of methyl ugenol combined with an insecticide to destroy males of the Oriental fruit fly is another recent accomplishment in the attractant field. Attractants are used for housefly control in Florida through the use of sugar containing phosphorus insecticides.

Research is being conducted with growth regulators for insects. This is effective on minor sucking insects but so far has not been effective for the important chewing species.

Chemical sterilants have been effective in controlling certain insects. Gamma irradiation is used to sexually sterilize the screwworm with subsequent mass release of sterile males for eventual eradication.

Repellents have been investigated extensively but little research has been devoted to the protection of agricultural crops. Although destruction is regarded as the best means of insect control, there are many situations where repellents might be more desirable than toxicants, since this method may not lead to species resistance. In screening chemicals for insect control, we place too much emphasis on materials that kill insects upon contact. A chemical that renders an insect incapable of feeding or reproducing may provide adequate control though not immediate death. Chemicals which induce starvation show promise. After consumption, there is substitution of part or all of the chemical for some hormone or enzyme vital to life. These are called anti-metabolites, and control loopers on lettuce better than conventional insecticides.

Pesticide use is expanding in the field of public health. In some areas, aerial sprays for the control of mosquitoes have become routine. This is especially true of East Coast resort areas where an over-abundance of mosquitoes has depressed business and real estate values. The use of insecticides to eliminate disease carriers such as malaria, encephalitis and other human ailments is increasing in America and abroad. There is also increased use of insecticides for flies, cockroaches, termites and other household pests.

Feed Chemicals

Simultaneous with increasing human populations, livestock numbers in the U.S. have increased approximately 7% during the last 10 years. Integration both horizontally and vertically has been a significant development in the feed industry and contributed to more efficient production of edible flesh at lower costs. The increased production of meat can be attributed to improved nutrition and increased feeding rates. There has been a 33% increase in feeding rates to beef animals in the last decade and a significant trend is evident for feeding high protein supplements with grain. This has resulted in an improved rate of animal gain and a saving of feed. A decade ago, broiler chicks gained 1 pound of flesh for every 2.9 pounds of feed. Today equivalent gains are made by commercial broilers with as little as 1.9 pounds of feed. Feeding efficiencies are improving for other domestic animals also, with the weight gain of hogs approaching 2.5 to 1 from 3 to 1 and beef 7 to 1 from 9 to 1.

Amino acid supplementation, particularly with methionine and its hydroxy analogue, have become important additives in the commercial production of poultry and eggs.

Electronic computers are becoming important for linear programing in the formulation of diets for animals. Every constituent can be assessed for its complete nutritional contribution. A true nutritional comparison of all ingredients can be obtained in this way so that the proper formulation can be selected at the least-cost. All feedstuffs are included so that the cost can be calculated to obtain equivalent performance for various basic ingredients. This procedure is presently utilized for linear programing diets for chickens and will ultimately be used in swine, calves and steers. This will provide, for the first time, a true evaluation of ingredients on a nutrient contribution basis.

Fishmeal is being used as a protein supplement in feeding poultry. The fats and oils present in feed ingredients require a specific type of oxidation protection since oxidation in poultry feeds produces encephalomalacia and other chick nutritional diseases. The addition of Santoquin*, an antioxidant, prevents growth retardation and toxicity due to oxidation of fats and oils in feeds. Since the in vivo activity of Santoquin is analagous to that of Vitamin E, this antioxidant has largely replaced the need for supplemental Vitamin E in poultry and animal feeds.

In conjunction with increased feeding rates in swine and beef cattle, antibiotics are used extensively to prevent growth retardation due to certain micro-organisms in the gastro intestinal tracts of the animals. With the control of bacterial and fungal diseases in animals through use of chemicals, virus diseases are more easily recognized. It appears that animals are better able to resist the virus diseases, provided bacteria are controlled and the animal has adquate housing with proper ventilation. Good housing has also resulted in feed economy through a reduced requirement for heat energy.

The field of human nutrition has been receiving more attention in recent years. Human nutrition has not advanced to the degree that animal nutrition has and probably never will since human viscera are not crushed and analyzed after the conclusion of the

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* Trademark of Monsanto Chemical Company, St. Louis, Missouri, Reg. U.S. Pat. Off.

feeding trial. It has, however, been proved that protein enriched bread is beneficial to humans. Experiments are presently being conducted in Ghana to determine the nutritional value of adding vegetable proteins supplemented with MHA to protein deficient diets. The use of chemicals will now permit technically underdeveloped countries to improve the nutritional value of their indigenous proteins for direct feeding to humans.

There are other fields in which chemicals will be of service. There is expected to be substantial increased sales in the home and garden market. Forestry and wildlife management are newer market areas which show considerable promise for the future. Chemicals are being used for such things as repelling animals from tree seeds to permit seeding of large areas by helicopter; for killing eels to permit rejuvenation of the white fish industry in the Great Lakes; and to control foliage in forest areas to improve the habitats of wildlife.

These are trends of today. The trends of tomorrow will have vastly greater far-reaching effects on the agricultural-chemical industry. We are living in a period that is dominated by a scientific and technological revolution as potent in its impact upon our lives and future as the Industrial Revolution of the 19th century. For the first time in history, it is possible to foresee the time when farm products will be available to the world's peoples.

Tremendous strides have been made in the production of food in the last 150 years. At that time, one man on the farm supplied his family with food and a little extra. In 1862, 1 farmer in the U.S. produced sufficient food for 4 persons, most of whom lived on farms. Only 25 years ago, one man on the farm could supply 8 or 9 others with food, and currently, one man can feed more than 25 others.

Increased unit farm production in North America has been accompanied by an increase in population, an increase in farm size, and a decrease in the utilizable cultivated acreage. This increased production was naturally accompanied by an increase in farm size to accommodate the capacity of the individual producer. The number of farms in Canada has decreased from 270,000 to 219,000 during the last 10 years. The total number of farms in the U.S. decreased by approximately 1 million or 22.6%. A similar trend has been occurring in Britain, a trend that is likely to be accentuated with her entry into the European Common Market.

Improved technology in the agricultural field has resulted in over-production of foodstuffs in North America, particularly corn, wheat and dairy products. In Canada there has been a feverish search for production of alternate crops; and the livestock industry has utilized significant quantities of surplus grains. Millions of acres of corn and wheat in the U.S. have been retired from production to decrease agricultural food surpluses. This has occurred despite an increase in the U.S. population of 6,000,000 persons in 1800 to the present 175,000,000 persons. The U.S. Census Bureau forecasts a population of 200,000,000 people by 1965 and 270,000,000 by 1980, representing a doubling of the population during the 40-year period 1940-1980. By 1980, food requirements on the North American continent will be doubled.

The United Nations reported in 1960 that more than 65% of the world's 3 billion people are underfed. Most experts agree that 75% of the world's peoples go to bed hungry. Yet only about half of the food presently produced reaches human stomachs of the world because of waste. This is a somber reflection in a continent in which surpluses of human foodstuffs abound. It is tragic that the problems of food distribution have not been surmounted, making surpluses available to people in need.

One of the major problems is to bolster industrial production in under-developed nations so that they may produce food and provide goods to be used in trade for western food surpluses. The United Nations Food and Agriculture Organization through its Freedom From Hunger campaign and technical assistance programs of western nations (e.g. the U.S. Food for Peace program) are working actively in Asia, South America and Africa to bring this about. There is evidence of some success. In recent years, Japan has changed from an insignificant importer, to Canada's biggest importer of wheat. The recent trade agreements with China for the purchase of Canadian wheat appears to be a step in this direction. India has periodically purchased Canadian wheat, and is presently buying 587,000,000 bushels of wheat and 22,000,000 bushels of rice from the U.S. A considerable proportion of the rupees involved in this transaction will be loaned to India to finance her economic development. Pakistan is presently considering Canada as a source of grain for import. With the technological awakening of non-industrial countries and subsequent increased trade, demands for food will be felt in North America.

Present food requirements for the people of the world is more than 3 1/2 trillion pounds annually of food of high nutritional content. Something near half this amount is available with present practices, and the production of all of our agricultural lands utilizing all of our technological advances would be hard put to meet the requirements. Furthermore, the human population has doubled in the last 100 years, and a study of the rate of increase indicates that it could double again during the next 40.

In western Europe, agricultural lands are not able to produce sufficient foodstuffs for their present needs. As a result, uneconomical producers are weeded out by standards of minimum production which are established by governments. Producers not able to meet these standards are replaced by those who do. The time is coming in North America, also, when food production will of necessity be increased and production costs decreased through displacement of inefficient producers.

It should be the aim of every well fed human to make every effort to help hungry people to help themselves. A larger measure of this responsibility must of necessity fall on those of us in fields related to production, preservation and distribution of agricultural foodstuffs.

The role of chemicals in accomplishing this will be unprecedented in scope and develop into some of the most widespread and fundamental practices in the agricultural industry. The petroleum industry with its important basic chemicals like benzene and naphtha will be the foundation for the coming chemical revolution as it was for farm mechanization in agriculture.

DISCUSSION

Mr. R. F. Steel, Canadian Chemical Co: I was just wondering, Dr. Selleck, as we use more and more of these different 'cides on our edible products - what about the effect on human health and the control of these things. Probably even a more difficult problem, what about the reconciliation of public opinion. If you don't mind I'd like to ask one more personal problem and that is a very lucrative one; what about the control of quack grass?

Dr. G. W. Selleck, Monsanto Chemical Company, St. Louis, Mo.: I'll answer the last question first. There are chemicals to control quack grass but we're looking for better ones. But in the field dalapon or TCA in conjunction with tillage works well. Another chemical, amino triozol, has also been used.

This problem of public opinion pertaining to chemicals to use is the really important one. I'm taking responsibility for what I say. This fiasco of the cranberry industry was given too much publicity so it makes the consumer afraid to turn around and look at a chemical. This is not his fault. There are other reasons for this as you know. As more and more chemicals are being produced certainly there is a greater danger, of human health. The regulations are becoming more and more stringent. This is recognized. I think it's true to say that chemical companies generally recognize their responsibility. Certainly in my recent experience in my company I as sure as with other companies, that the tests in this way are endless - from the point of view of buildup in the feeding to animals for a long period of time - and whether there is a residue in the soil and all of this, I have every confidence that industry has the responsibility to take care of these problems before they arise. There is too much public opinion by individuals getting up and giving us a tirade on the danger to human health without really knowing the facts.

THE EFFECT OF NATURAL GAS ON THE GROWTH OF WESTERN CANADA'S FERTILIZER INDUSTRY

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Mr. Wilkinson was born in Montreal. He received his chemical engineering degree in 1933 from McGill University. He was assistant to Director of Chemicals and Explosives Division, Allied War Supplies Corporation from 1940 to 1943. In 1943 he joined The Consolidated Mining and Smelting Company of Canada, Limited and is at present Manager, of the Chemical and Fertilizer Sales Division. He is a member of the Chemical Institute of Canada, the Director of the National Plant Food Institute, Washington, D.C., and was a delegate to the Fertilizer, Freedom from Hunder Campaign, Food and Agricultural Organization of the United Nations held in Rome in 1960. He has developed factual information on World Fertilizer Conditions by personal visits to such underdeveloped areas as India, Pakistan, Thailand, Malaya, Indonesia, Philippines and Korea.

To discuss fertilizer with an informed technical group attending a Petrochemical Symposium, appears, at first consideration, to be stretching the word "Petrochemicals" a little far, and yet it is a fact that Canada's first major venture into petrochemicals was definitely related to the fertilizer field.

Before enlarging upon this development, it might be well for me to explain briefly what "chemical" fertilizers are and what they do.

Today's farm, particularly on this continent, is fast becoming a highly efficient business enterprise, in which land is the major resource and profits depend upon the cost of crop production from that land. The use of chemical fertilizers, weed killers, and insecticides, to increase agricultural production, combined with other modern soil, water and crop management practices are very necessary tools to efficient and profitable farming. Mechanization alone has almost cut in half the man hours of labour required for farm work in the last twenty years, while output per man hour has tripled.

Chemical fertilizers have contributed enormously to reduce farm production costs by increasing output per acre; they are today, highly efficient farm production tools and are offered for direct farm application in varying compositions depending on the crop being grown, and the plant food deficiencies in the soil. The basic plant food nutrients required by all plants for healthy growth are Nitrogen, Phosphorous and Potassium, together with lesser amounts of Calcium, Magnesium, Sulphur, and a host of micro nutrients or minor elements. Today's fertilizers are often tailor-made to meet the specific requirements of specific soils and crops. The label on the package or bag of fertilizer you buy for your home garden possibly reads 5-10-5, which guarantees that it contains 5% Nitrogen, 10% Phosphorous as P_2O_5 and 5% Potassium as K_2O and these elements always appear in the same relative order in the analysis shown. For instance, the major fertilizer used on Canadian Prairie grain farms is 11-48-0 containing 11% Nitrogen and 48% P_2O_5 or 59% total plant food as compared to the total of 20% plant food contained in 5-10-5. This higher analysis for farm use is indicative of a definite trend towards an increasing demand for higher analysis fertilizers in order to effect substantial savings in transportation, distribution and application costs. Similarly, a significant trend towards bulk shipping and blending, and custom application of solid fertilizers, has been in evidence over the past two years to meet competition from the increasing direct application of high analysis liquid fertilizers on the farms on this continent.

Farmers are today much better informed as to their soil and crop requirements in specific areas through information constantly being developed by university and governmental agricultural departments. The Canadian Prairie Universities have done, and are continuing to do, excellent work in this connection. A striking example of this is the pioneer work done by the University of Saskatchewan, in the use of radio-active isotopes to measure the relative uptake of phosphorous in the growing plant from added chemical fertilizer and from natural occurring soil phosphorous. Their technique has been adopted for similar and related studies across the continent. The University of Alberta has done extensive work on the values of pasture fertilization in increasing the yield of meat, and Manitoba is presently concluding an exhaustive study on the general economics of fertilizer use as related to farmers motivations. The chemical fertilizer industry today, both from a producer's and consumer's point of view, has in the Western World, become a definite science and it only remains for man to learn how to effectively control weather conditions, so that optimum sunlight and rainfall can be assured in specific growing periods, in order for us to have complete control over our food production. However, this will probably be as tough a nut to crack as the economic distribution problems inherent in the build-up of surplus food supplies on this continent, while millions in under-developed countries continue to live on a mere subsistence diet.

I would like now to revert to my topic and develop the major part played by Natural Gas as a basic raw material for fertilizer manufacture in Western Canada.

We are all aware of the long search for a practical industrial process for the fixation of Nitrogen from the air culminating some fifty years ago in the Haber Bosch process, for the synthesis of Ammonia by direct combination of Nitrogen and Hydrogen. The fundamental principle of the Haber Bosch process is still utilized in Ammonia synthesis but modifications in equipment design and operating techniques have been many, and there are a wide variety of process choices available today.

For Ammonia synthesis, Nitrogen can be obtained by cold temperature fractionation of air or by combustion of the oxygen component of air with coke or other fuels. Hydrogen can be obtained by the electrolysis of water, from coke-oven gas or most recently from Natural Gas. Up until the last war, the coke Ammonia process, as it was called, was the main source of synthetic Ammonia production, which in turn, was converted to Nitric acid, mainly for explosive use, or in combination with Sulphuric acid to Ammonium Sulphate for fertilizer end use. In the coke ammonia process, Hydrogen and Nitrogen are produced from coke, steam and air using standard water-gas and producer-gas generators. Air and steam are blown through incandescent coke alternatively, and in correct proportions to produce the required synthesis gas mixture, and after removal of Carbon Dioxide and Carbon Monoxide and purification, the gas is converted to Ammonia at high temperature and pressure in the presence of a suitable catalyst.

Total Canadian production of Ammonia, prior to the war, was around 110 tons per day from two companies, the major portion of which was produced at Trail, B.C. from Hydrogen obtained from the electrolysis of water. Today, Canada's production is over 1,650 tons per day of Ammonia, with seven different companies producing and the major part of the Hydrogen required is obtained from Natural Gas. This phenomenal growth was triggered at the start of the last war by the decision of the Department of Munitions and Supply, to expand as rapidly as possible, the production of munitions and explosives in Canada to back up the United Kingdom production considered susceptible to knock-out bombing attacks. It was decided to expand Ammonia and equivalent Nitric acid production immediately, and government-financed plants were erected in Welland, Ontario; Calgary, Alberta; and Trail, B.C., to this end. The Welland Ammonia plant operated by the American Cyanamid Company was based on the coke Ammonia process as a source of Hydrogen as was part of the Ammonia expansion program at Trail, with additional facilities at the latter plant being provided by expansion of the Consolidated Mining's electrolytic Hydrogen plant. However, the most interesting and pioneering decision was to erect a new plant at Calgary to manufacture Ammonia from Natural Gas as the basic raw material, and this was to become the first plant of its type in the World and the first petrochemical operation on a large scale in Canada.

The steam-methane process for the production of Hydrogen employed at Calgary was developed in England by Imperial Chemical Industries. The only raw materials entering the plant are Natural Gas, Water and Air. In the Hydrogen plant, dry preheated Natural Gas, with all Sulphur compounds removed is reacted in a reform furnace with steam in the presence of a catalyst. The gas produced in the reform furnace is a mixture of H_2, CO_2 and CO. N_2 and additional steam are then added to the stream and the mixture fed to a CO converter. In the CO converter, CO and steam in the presence of a catalyst react to form CO_2 and Hydrogen. The gas stream leaving the CO converter consists mainly of N_2, H_2, and CO_2 with a small percentage of CO. This mixed gas stream then passes through a purification section to remove CO_2 and the small quantity of CO present. The mixed gas stream after purification consists of N_2 and H_2 in the ratio of 1 : 3 which is compressed and synthesized to Anhydrous Ammonia. The Nitrogen for the process is produced in Nitrogen generators which burn oxygen from air with Natural Gas.

Since 1941, when the plant began operation, nearly fifty-nine billion cu. ft. of Natural Gas have been used in the Calgary plant for Ammonia production, and a further thirteen billion cu. ft. have been used for the production of process steam. Present operations are consuming nearly five billion cu. ft. per year.

While the original purpose and design of the Calgary plant was for the production of Ammonia, Nitric Acid and Ammonium Nitrate, the latter in crystalline form, from the interaction of Ammonia and Nitric Acid, it shortly became evident that Ammonium Nitrate was not going to be required in the quantities estimated for explosive and munition requirements, due to the failure of enemy bombers to more than temporarily disrupt production in the United Kingdom. However, the Western Allies' overall requirements for Nitrogen for war purposes had necessitated diversion of agricultural Nitrogen to this end and this had created a large deficiency in available fertilizer with a consequent serious reduction in food supplies. With the United States and Canada being called upon to increase crop production for the rest of the Western World, the oversupply of Ammonium Nitrate at Calgary and Welland represented an important potential source of agricultural Nitrogen to further this endeavour. Crystalline Ammonium Nitrate, however, due to its very hygroscopic nature, is very prone to severe caking and for this reason, it had not, to any extent, been utilized pre-war for fertilizer purposes, except in such products as Cal Nitro and Ammonium Nitrate lime where heavy dilution with limestone and clay controlled the caking, but at the same time decreased its effectiveness as a fertilizer. While in the emergency, some of the crystalline product was shipped from Calgary and Welland to United States fertilizer manufacturers and distributors, it was evident that no sizable movement could be developed until the problem of the bagged "tombstones", as they were called, was eliminated. Teams of production, research and advisory governmental personnel, tackled the problem and in the fall of 1943, after intensive development research, a process was evolved by Cominco at Calgary, to produce Ammonium Nitrate in the form of free flowing pellets by spraying hot concentrated solution down a ninety ft. tower, against a rising flow of air. This was the famous prilling process, the patent for which is held by the Canadian Government and which became the backbone for the subsequent rapid growth of the Ammonium Nitrate fertilizer industry on this continent, which today produces in the order of 3,500,000 tons of prilled Ammonium Nitrate annually. The Calgary plant was operated by the Consolidated Mining and Smelting Company on behalf of the Canadian Government during the war and purchased by that Company in 1946, along with the government installations in Trail. Both Calgary and Trail Ammonia operations have been expanded since that time and with fairly recent completion of the gas pipeline into Trail, the coke Ammonia operation has been converted to the Natural Gas steam methane process. The development of the Forward process for the chemical leaching of nickel ore by Sherritt Gordon Mines at Fort Saskatchewan, Alberta, required an Ammonia plant at that location. Here again, the Natural Gas process was selected with a resultant output of Ammonium Sulphate for fertilizer use. In 1957, Northwest Nitro Chemicals was formed as a strictly basic fertilizer producer and their plant at Medicine Hat, Alberta produces Ammonium Nitrate and Ammonium Phosphates utilizing Ammonia from Natural Gas as the basic material. In addition, both Sherritt Gordon and Northwest Nitro, use gas engines driven by Natural Gas to drive compressors and a portion of their power requirements are provided by steam driven generators using steam from Natural Gas fired boilers. Combining these requirements, nearly 14.5 billion cu. ft. of Natural Gas are used annually in Western Canada's fertilizer producing plants for a combined output of nearly 250,000 tons of Anhydrous Ammonia per year. Solid fertilizer produced from this Ammonia either in straight nitrogeneous materials or combined with phosphorous, totals over 900,000 tons of high analysis products. This is a far cry from the 35,000 tons of Ammonia and 280,000 tons of solid basic fertilizer materials produced annually in this area prior to the war.

It is therefore evident that Natural Gas has played a predominant role in the expansion of fertilizer production in Western Canada. There is no doubt that, without the advantage of this relatively inexpensive source of Hydrogen, Canadian production would not have expanded to the extent it has, nor would we have been in the position to so successfully compete in export markets. Of the 900,000 tons of solid fertilizer produced in the four Western provinces, over 750,000 tons find their way into export trade, mainly into the Western half of the United States. Canadian fertilizer is sold as far south as the Mexican borders of Arizona and California, and sometimes across that border; as far east as Wisconsin and Illinois, and through the Dakotas to Nebraska and Iowa; in all, some sixteen States are serviced from these Western plants, not to mention the new States of Alaska and Hawaii. Products include the purely nitrogeneous materials, Ammonium Sulphate, Ammonium Nitrate and Urea, the latter a recent and growing addition to the Canadian product line; combinations of Nitrogen and Phosphorous, such as mono-Ammonium Phosphate 11-48-0, and Di-Ammonium Phosphate 16-48-0, plus intermediate analyses to meet the recommendations of governmental and university agricultural authorities, such as 27-14-0, 23-23-0, 16-20-0, 24-20-0, and 18-36-0 and lesser amounts of combinations with Potassium such as 13-13-13 and 14-14-7. In addition, some 60,000 tons of liquid fertilizers are exported to the Northwestern United States for direct application to the soil, including Anhydrous and Aqua Ammonia, Ammonium Nitrate and Ammonium Nitrate-Urea solutions and nitrogen solutions containing Sulphur for specialized use. Thus fertilizer has become big business in Western Canada and much of the credit must go to Natural Gas. Western Canada's export fertilizer trade to the United States has grown in the face of tremendous expansion of fertilizer productive capacity in that country, much of which is centered in and around the area in which Canadian products are sold. With the success of Calgary Natural Gas Ammonia plant, the United States Government in their expansion program for war purposes, built six wartime plants based on the same process. Today in the United States, there are more than thirty Ammonia plants utilizing Natural Gas as the basic raw material. Many of these plants also produce Ammonium Nitrate in prilled form, using the process developed at Calgary. Over 7,000,000 tons of Ammonia are produced annually in the United States and news of expansions and planned new capacity continue to appear in the industrial press. Actual fertilizer consumption in North America, in terms of the plant nutrients of Nitrogen, P_2O_5 and K_2O combined, increased from 2,700,000 tons in 1945/46 to 4,000,000 tons in 1949/50 and to over 7,000,000 tons in 1959/60, and even though this has been a phenomenal growth, consumption of fertilizer nutrients per acre of arable land on this continent is still only one-fifth of that so used in Western Europe. With the World population explosion anticipated over the next fifty years, the economic problems involved in distributing food and fiber more equitably among the nations of the World must be solved if people of the under-developed countries are to be provided with an adequate diet, and all signs point to a continued growth in fertilizer demand and use on this continent, as an important tool to realize this aim.

Reverting to our fertilizer export trade to the United States, I would like to outline one of the problems facing all fertilizer producers. The fact that about two-thirds of all fertilizer consumed on this continent is required for application from March through May is doubtless the biggest headache of the fertilizer business. Distribution and warehousing problems to ensure farm delivery when the farmer wants it necessitate spot inventories in hundreds of locations. To cite an example in our own case, as of March 1st, we had a total fertilizer inventory of some 300,000 tons spread over nearly 1,000 locations in Canada and U.S.A. awaiting spring delivery.

With the advent of the Natural Gas process, it is interesting to note that such major oil companies as Standard of California, Indiana and Ohio, Union Oil, Phillips, Texaco, Sun Oil and Shell are all directly or through subsidiaries major producers of Ammonia for fertilizer production in the U.S.A. All with the exception of Shell Chemical, who were pre-war producers and Phillips, who bought a large government war plant, have entered the field in the last ten years.

The United States, while the largest export field for Canadian produced fertilizers, is not the only export outlet. In the last ten years, Western producers have exported offshore through Pacific Coast ports well over 1,000,000 tons of solid fertilizers. These exports have been made to the Philippines, Indonesia, Korea, Formosa, China, Thailand, India, Pakistan, Greece, Spain, Mexico, Columbia, Peru, Venezuela, Chile and Central America, and against extremely tough competition pricewise from European and Japanese exporters. It will interest you to know that Europe and Japan each have exportable surplus fertilizer production of over 1,000,000 tons annually, mainly in the form of Ammonium Sulphate and Urea. The United States International Cooperative Administration and its successor, the Administration for International Development or A.I.D., have provided funds for fertilizer purchases to such countries as Korea, India and Pakistan. The Canadian Government under Colombo plan assistance has also exported Canadian fertilizer to Pakistan and India. The continued expansion of fertilizer requirements in these under-developed over-populated areas is very necessary for their economic development.

Dr. Frank Parker of the Food and Agricultural Organization of the United Nations in Rome stated recently:

"A major objective of the World is to accelerate the modernization of less developed nations, increase their productivity and improve income and living standards. It is now recognized that particularly in the earlier stages of development, high priority to agriculture must be given. Fertilizer has become an important factor in agricultural production in comparatively recent years, but even now, only a very small percentage of the World's crop land is fertilized."

The government of India has also stated that : "the rate of growth in agricultural production is one of the most limiting factors in the progress of Indian economy." Taking India as an example of the importance of adequate fertilization for food production, they are now beginning their third five-year plan for economic development.

In the five years ending June 30, 1961, India had planned for an increase in consumption of nitrogeneous fertilizers from 150,000 tons of Nitrogen to 373,000 tons annually and actually achieved a consumption rate of 220,000 tons during 1960/61; in the next five years ending June 30, 1966, they are planning to increase this consumption to 1,000,000 tons of Nitrogen annually, equivalent to 5,000,000 tons of Ammonium Sulphate or 2,250,000 tons of Urea as round figures, an astronomical growth but very necessary if they are to reach their economic goals. To attain this growth, new indigenous production must be established, and is being encouraged, by the Indian Government by various means in the hope of reaching a home production of some 760,000 tons of fertilizer nitrogen capacity by 1966. Even if this almost impossible target is reached, imports would have to more than double from present levels to meet the overall requirements. Similar situations prevail in Pakistan and mainland China. The latter recently closing contracts for 1962 supplies of 900,000 tons of Ammonium Sulphate from Europe and 100,000 tons of Urea from Japan.

The basic point of these considerations as far as Western Canadian producers is concerned is that these markets will continue in the foreseeable future to be possible areas for fertilizer exports. Whether we can successfully exploit these opportunities however depends on numerous factors, the principal ones being our cost of production, our inland freight rates to ports, port charges, ocean freight rates and last but not least, the level of World competitive prices. These latter are often affected by direct or indirect subsidies paid by foreign governments to domestic producers in the export trade at the expense of internal domestic prices. Apart from Colombo plan sales, no such subsidy is available to Canadian producers to assist them in their export endeavours. Offshore export of fertilizers is therefore both a risky and challenging business and I doubt seriously that any expansion of Western Canada's nitrogeneous fertilizer production could be justified solely for this purpose.

In conclusion, I would like to mention the growth of Western Canada fertilizer consumption over the last ten years. The four Western provinces in the year ending June 31, 1951, used some 97,000 tons of basic fertilizer materials for direct farm application; ten years later in 1961, this figure had grown to 183,000 tons or nearly doubled. Contained Nitrogen in these totals had moreover increased from 12,500 tons to nearly 32,000 tons in other words, nearly 100 tons of Ammonia per day is now finding its way into Western soils in the form of fertilizer. While this represents a major growth in fertilizer consumption, the application rate per acre of arable land in these Western provinces is still relatively very low and this points up the vast potential for increased food production available for the future from our Western farms.

Canadian Natural Gas has played a very important part in the development of fertilizer production in the last 15 years and will, no doubt, continue to enable Canadian fertilizer production to expand competitively and in line with the World's increasing fertilizer consumption rate.

<u>Reference</u>

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TRANSPORTATION - ITS INFLUENCE ON PETROCHEMICAL MANUFACTURE IN ALBERTA

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Mr. Simmonds was born in England and received his primary education at Bickley Hall Preparatory School and Brighton College. He graduated from Oxford University with an M.A. and B.Sc. He did research and development work with Lever Bros. & Unilever Ltd., and for five years was senior lecturer in chemical engineering at the University of Durham, Kings College, Newcastle-on-Tyne. He came to Canada in 1952 and continued his research work as assistant to the Director of Research with Dominion Tar & Chemical Company in Montreal. He joined the development department of Canadian Industries Limited in 1956 as a chemist. Mr. Simmonds is a member of the nomination and education committees of the Institution of Chemical Engineers (U.K.) and a member of the executive committee of the Montreal Section of the Chemical Institute of Canada.

The second paper in this symposium on economic conditions deals with transportation and its influence on the petrochemical industry in Alberta. This paper will bring out that modifications of railway freight charges have improved Alberta's ability to compete as a location for petrochemical manufacture during the period of varying selling prices over the past decade. However, increasing world competition in petrochemicals is expected to hold petrochemical prices down. Freight rates on raw materials, fuel, and products will therefore remain very important to Alberta producers, and any developments which can be made to reduce costs in this area will assist Alberta to attract additional petrochemical manufacturers.

In his historical survey of the petrochemical industry in Alberta yesterday, Mr. Istvanffy showed that industry's choice of an Alberta location for petrochemical manufacture was due to specific advantages in raw material or fuel costs at the time concerned. Only in the case of sulphur was an Alberta location dictated by other considerations. Today Alberta's original advantages in raw materials and fuels have been lessened by widespread discoveries of natural gas and crude oil, which have brought about a world surplus in the case of crude oil; by the development of large export and extraprovincial markets for crude oil and natural gas, which have resulted in price structures determined primarily by conditions in these markets rather than by conditions in Alberta; and by changes in the price of petrochemicals, many of which have been downwards.

Looking back ten years, Alberta had one ammonia plant and confidently expected that many other petrochemical manufacturers would gravitate towards the newly found feedstocks; today's conference is evidence of an awareness that location of petrochemical plants close to raw materials and/or fuel does not automatically follow. If Alberta wants more petrochemical plants, its raw material, fuel, and other costs must obviously be significantly lower than those in the finished product market areas.

The criteria governing the selection of an Alberta site for petrochemical manufacture were recently reviewed in a publication of the Oil & Gas Conservation Board(1). A move towards Alberta will be encouraged, if the raw material and fuel cost component in a petrochemical product's full plant cost is reduced relatively to any increase in transportation costs on the product itself. Such a move would be favoured according to the Report by several factors, which include:

(a) a high price to weight ratio in the product;
(b) a high raw material cost content in the product;
(c) a high energy cost content in the product.

In addition, one might mention the following factors:

(d) long-term assurance of supply of raw materials or fuel, or both at reasonable prices;
(e) the existence in, or close to, Alberta of other non-hydrocarbon raw materials or products, which lend themselves to integration with petrochemical manufacture, such as forest products, metal ores and concentrates, phosphate rock, salt, sulphur, etc.
(f) specific market characteristics; these include local demands for petrochemicals by agriculture, the oil & gas, and other industries; products which can be exported south to the United States against little or no tariff; exports to other countries, particularly from the West Coast; products for other export industries; and special products such as helium.

Differences in construction, labour and other costs between different sites exist and must also be counterbalanced by advantages in raw material and fuel costs.

The general situation in Alberta as a site for petrochemical manufacture can now be examined, and in considering the figures in Table 1, it is helpful to bear in mind that on chemicals and plastics in the 50-5¢/lb. price range a 1¢/lb. increase in delivered cost is equivalent to a reduction in gross profit margin of 2% to 20%.

In an article published in "Chemistry in Canada" for February, 1961, Sidjak of Imperial Oil suggested that, for a petrochemical made at the rate of 50 million pounds a year with a yield on raw material of 50-60%, a net advantage on raw material and

Table 1. Cost Differential in favour of Prairie versus Ontario-Quebec location for a major petrochemical in cents/lb.

		Sidjak	Present paper
Raw material + fuel		1	(1.0 to 2.0)
Freight on product,	Feb. '61	-1.9	-(1.8 to 2.5)
Freight on product,	Aug. '61		-(1.0 to 2.0)
Net advantage	Feb. '61	-0.9	+0.2 to -1.5
Net advantage	Aug. '61		+1.0 to -1.0

fuel costs of approximately 1¢/lb. of product would exist in favour of a Prairie location. However, in view of the wide variety of petrochemicals and conditions under which they are manufactured, it may be fairer to turn the figure of approximately 1¢/lb. of product into a range of approximately 1 to 2¢/lb., as shown.

The freight rates quoted by Sidjak were 1.9-4.0¢/lb. The higher commodity rate figure of 4¢/lb. has been omitted from Table 1, since at a volume of 50 million pounds a year freight rates closer to a range of 1.3-2.2¢/lb. could probably be negotiated at the present time. After making an allowance for freight on products from the main eastern petrochemical centres of Sarnia and Montreal East/Varennes to the Toronto market area, a net freight penalty to an Alberta producer of 1.8-2.5¢/lb. existed early in 1961. This has been reduced to 1.0-2.0¢/lb. by freight reductions granted later the same year.

In fairness to the railways it should also be pointed out that, while Sidjak's statement that "in the postwar period rail freights have increased steadily" may be generally true, it is not true for petrochemicals made in Alberta during the past ten years or so. Thus it is true that class 5 rail rates have increased by 10% in the past nine years, from 3.53-4.12¢/lb. But as the result of competition between the carriers the rates on polyethylene have fallen from 3.53¢/lb. in 1954 to the present agreed charge of 1.3¢/lb. on 70,000 lb. carloads where the shipper contracts to ship at least 70% by rail. Methanol rates have fallen from a rate of 2.52¢ in 1953 to a 1.40-2.18¢/lb. range of agreed rates today; fertilizer rates at 0.92¢/lb. for 110,000 lb./car shipments are very slightly less than 0.96¢/lb. rate existing in 1953.

The relationship which transportation costs bear to selling prices is also significant and is shown in Table 2. During the past eight years there has been a sharp decline in the price of polyethylene, from 40¢/lb. to 25¢/lb. for standard grade, methanol has maintained an almost constant price of 30¢/U.S. gallon, while the price of a fertilizer such as ammonium nitrate has risen slowly from $57/ton in 1949 to $64/ton today. Table 2 shows that the percentage of transportation cost to selling price has fallen in each of these very different cases. It seems legitimate to conclude that in regard to transportation costs Alberta is at least as suitable site for the manufacture of these petrochemicals as it was ten years ago.

Table 2. Transportation cost from Alberta to Eastern markets as % of selling price of comparable grade for three Alberta petrochemicals

	1953	1961/2
Polythene	9%	5%
Ammonium Nitrate	31%	29%
Methanol	52%	32%

However, in thinking of the future, it is necessary to consider not only transportation but the other cost variables affecting the decision whether to locate a plant in Alberta or at other sites in Canada with access to ocean transport, in particular raw materials, and fuel.

A world surplus of crude oil is expected to exist at least till the end of this decade. In addition, increasing quantities of natural gas liquids, liquefied gases, and even in the near future of liquefied natural gas, are becoming available. In view of this surplus situation, it is expected that world hydrocarbon and fuel oil prices may decline, especially in areas which are subject to Soviet intervention. Petrochemical feedstocks are in increasingly plentiful supply. In the case of light naphtha for cracking to olefins, it has been predicted that the price at the refinery could go as low as 20% above the delivered price of crude oil.

The Alberta Government recently decided not to allow surplus natural gas liquids to be committed to a single export market. In so doing, it has established a hydrocarbon raw material situation, in which condensate is tied, pricewise, to crude oil, because of the demand for it by petroleum refiners; whereas propane, butanes and natural gasoline are not tied pricewise to crude oil. Along with other users of these materials, petrochemical manufacturers are free to negotiate contracts for these hydrocarbons on as favourable terms as they can secure.

Turning now to factors which govern fuel prices, the world surplus of crude oil has the effect of holding fuel oil prices down at all points in Canada with access to the sea. It also tends to hold down the price of Canadian crude oil and therefore of domestically produced fuel oil. A petrochemical producer located on the St. Lawrence or on the west coast, is therefore fairly certain of fuel costs related to world energy prices, which may be expected to be competitive for the next ten years of operation of a petrochemical plant. During this period fuel oil may also meet increasing competition from coal, as the pipelining of coal slurries in water or in oil is developed. In Alberta natural gas prices are largely tied to export gas prices, although petrochemical requirements for natural gas have a different basis than that which governs exports.

There are several other points, which must be made in regard to the collection and supply of feedstocks for petrochemical purposes in Alberta. A 50 million pound a year plant with a 50-60% yield on raw material, the case considered in Table 1, would require in the range of 1,000-1,700 barrels per day of propane, or butanes, or natural gasoline. This amount of raw material represents a sizeable fraction of the surplus volumes estimated to be available in different areas in the province. Since these raw materials are produced in conjunction with natural gas and crude oil, the amounts available may vary with time due to change in reservoir conditions. Changes in reservoir conditions may in the course of time require changes in operating techniques to maximize crude oil recovery; and the varied locations of natural gas liquid recovery plants in the province may make transportation of raw materials from them to petrochemical centres such as Edmonton, in the quantities required, sufficiently expensive to nullify, partly or in whole, the advantage of low prices. In addition, the variety of owners of hydrocarbons with conflicting interests, may require lengthy negotiations and protracted hearings before Government agencies before a supply of feedstocks suitable in volume and price can be obtained. These facts-of-life must be viewed realistically against the comparative simplicity of petrochemical projects elsewhere, such as the new Shawinigan Chemicals project, in which foreign crude is to be pipelined or shipped to Varennes on the St. Lawrence, and a naphtha fraction separated and steam cracked to various petrochemical intermediates. Summing up, measures which facilitate the production of oil and gas do not necessarily also facilitate production of petrochemicals. They may do so, but equally well they may not do so.

As mentioned previously, a great deal has been done during the past decade in respect to transportation to keep Alberta competitive. For example, the railroads have exploited their advantages of long haul operations by eliminating sorting and by increasing the size and loadings of cars and tankcars; by through-routing trains, and by the use of computers to control their operations more precisely, etc.

These improvements have been spurred on by the growth of the trucking industry. The complex issues governing competition between rail and road transportation are the subject of the recently issued reports of the Royal Commission on Transportation. It is, of course, not yet known what action on the recommendations of the Commission will be taken in respect to freight charges. The emphasis in the Report on the need to identify, control, and reduce costs and to retain competition in this field appears helpful and will be welcomed.

In the area of pipelines the Research Council of Alberta and the University of Alberta have taken a commendable lead in research and development of new techniques. Their work on pipeline containers, sulphur and coal suspensions, and two-fluid flow in pipelines is well known and timely. The successful development of pipelines carrying ethylene, gilsonite slurry, coal slurries, molten sulphur, and woodpulp, and the development work on the pipelining of wood chips by the Pulp & Paper Research Institute of Canada, suggest that an era of wider usefulness for pipelines is arising.

A third possible method of reducing transportation costs lies in greater use of the river systems. This has been proposed for sulphur, and could be used for potash and other minerals and ores. It would require improvement of the Saskatchewan river system by Governments and possibly the development of collapsible containers or barges, such as the "Portolite" or "Dracone" types; its economics may repay checking by competent authorities.

However, it does appear that further large scale reductions in transportation costs are unlikely. The main room for improvement in Alberta's situation may well lie in fuller exploitation and adaptation of its raw material and fuel position for the manufacture of products of greatly increased value, such as a wider range of petrochemicals. Any steps therefore which will help achieve this and any developments which will help to keep transportation costs low, are likely to assist Alberta in sharing more fully in the great petrochemical expansion of today.

References

(1) Oil and Gas Conservation Board, Report to the Lieutenant Governor in Council dated June, 1961; Report to the Department of Mines and Minerals, June 1961.

(2) W. Sidjak: "Basic Petrochemicals", Chemistry in Canada, February, 1961, 23-26.

DISCUSSION

S. J. Dorst, The California Standard Co.: I was curious about your fuel cost advantage that exists on the prairies over Ontario. What fuels did you use in the two locations and about what cost per million BTU's are you considering for them?

Mr. W. H. C. Simmonds, Canadian Industries Ltd., Montreal, Quebec: I took a range of figures and in Alberta fuel gas is running around 18 1/2¢, the gulf coast figure is 20¢ interruptible. In Ontario it is 33¢ and firm gas will be around 50¢. Then for things like propane, butane and natural gasoline I took the Tuloma prices which were offered last year as being reasonably realistic then added in where necessary the effect of transporting liquids from a gas absorption plant to Edmonton. Remember a mass of figures were developed during the hearings last year on the disposal of natural gas liquid and this enables you to get an idea of the range of figures which you are using. Then in regard to refinery figures, there are a fair number published to the transfer prices of petroleum products inside refineries for example on Ethylene Manufacture by M. W. Kellogg and these give figures for Gulf Coast. Recent meetings in the AIChE there was a comparison made of the Gulf Coast and East Coast situation which parallels in some measure the situation between Alberta and say refineries in Sarnia, Toronto and Montreal East. In effect what you have to do is take all the figures you can find and work them all out and then average the result.

EXPANSION OF CHEMICAL INDUSTRY IN ALBERTA AND THE ESTABLISHMENT OF A FAVOURABLE ECONOMIC CLIMATE

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During the war years Dr. Donald was Director-General of the Chemicals and Explosives Production Branch of the Department of Munitions and Supply and again served the Government as Director of Chemicals and Explosives of the Department of Defence Production during the Korean crisis. Some interesting contributions include work on the Canadian chemical tariff for a group of major chemical manufacturers representing the industry and preparation of a brief and detailed studies on chemicals on behalf of the Royal Commission on Canada's Economic Prospects. In addition, under Dr. Donald's direction industrial surveys have been carried out in the Provinces of Manitoba, Newfoundland and Alberta. He is a member of the Chemical Institute of Canada, the American Institute of Chemical Engineers and, at one time, was Chairman of the Canadian Section of the Society of Chemical Industry. In addition to the O.B.E. award for his Government service during World War II, Dr. Donald received an honorary D.Sc. from his Alma Mater, McGill University and, in 1952, was awarded the Canada Medal of the Society of Chemical Industry.

Alberta has rapidly developed a large chemical industry. Ammonia from natural gas, oxygenated chemicals and polyethylene from L.P.G.'s, sulphuric acid from Alberta sulphur, caustic soda and chlorine from Alberta salt and natural gas -- all are substantial industries. The benefits of these industries to the Alberta economy are very substantial. Large capital expenditures have been made, employment has been provided, tax revenues have been created and, most important of all, the value of Alberta natural resources has been greatly enhanced. Nitrogen fertilizers manufactured from natural gas, and plastics and petrochemicals produced from L.P.G.'s are of much greater benefit to the Province than is the export of the equivalent quantity of natural gas and L.P.G.'s. The use of Alberta sulphur to produce sulphuric acid and of Alberta salt and gas for chlorine and caustic soda produces wealth from resources which would otherwise lie dormant.

The questions before us are how can further expansion of chemical industry, notably petrochemicals, be promoted; how can a favourable economic climate for further expansion be created; and how can government economic policy, through tariffs, taxes and other fiscal measures, aid and promote this expansion.

The basic reason for this symposium is the large new volume of L.P.G.'s becoming available from the oil and gas wells of Western Canada, and the necessity for finding new outlets for these products. As easily liquefiable gases they possess the advantage of being transportable as liquids which can be reconverted to the gaseous phase. These properties permit large scale distribution for domestic heating purposes and provide a convenient auxiliary storage for natural gas distribution systems.

Chemically, ethane, propane and butane are basic raw materials for certain petrochemical operations, particularly for the production of ethylene, propylene and butadiene. These, in turn, are building blocks for a large range of chemical products including plastics and solvents, notably polyethylene, polypropylene, vinyl compounds, glycols, and synthetic rubbers. L.P.G.'s are also the basis of a wide range of chemicals produced by the direct oxidation process: methanol, acetone, formaldehyde, etc. These physical and chemical properties give them certain market advantages over natural gas and the heavier hydrocarbons and, for such specialized uses, they command a relatively higher price. Where there are no specialized uses, L.P.G.'s must be sold in competition with other hydrocarbons, basically on a Btu. value.

L.P.G's are also available from oil refinery streams, and oil refineries can be a competitive source of supply and are frequently well situated in relation to markets. Comparatively recently, new techniques have been developed whereby ethylene, propylene and butadiene can be produced from naphthas and gas oils. As the by-products can be absorbed into the refinery stream, this essentially means that L.P.G.'s, as a raw material for petrochemicals, must compete with low priced gas oil or naphtha or, in the final analysis, with crude oil. Currently, this process is being operated at Sarnia and is providing Eastern Canadian industry with low cost ethylene, propylene and butadiene. Obviously the same techniques are available wherever crude oil is being refined on a large scale. It therefore becomes apparent that L.P.G.'s in Alberta provide no exclusive source of petrochemical raw materials and that their use for this purpose will be dependent upon competitive considerations.

To date the Alberta market has absorbed most of the available L.P.G.'s. The petrochemical industry in Alberta, utilizing L.P.G.'s, exports the greater part of its products outside of the Province and a large proportion outside of Canada. While some increase in the Alberta domestic market will undoubtedly arise, any further large scale usage of L.P.G.'s must, of necessity, be based on markets outside of Alberta. The Canadian market outside of Alberta is mainly in Eastern Canada. The most attractive export market is in the United States, but Alberta petrochemicals are also sold in other export markets.

I have already pointed out that Alberta petrochemicals must compete with similar products produced in Eastern Canada from crude oil moved by pipeline from Alberta. Pipeline transmission costs are low and freight rates on petrochemicals are relatively high.

Obviously, to overcome the freight disadvantage, production costs in Alberta must be sufficiently low to absorb this freight differential.

The Canadian tariff protection on petrochemicals varies from nil to 20%, but obviously has little bearing on the competition between petrochemicals produced in Eastern and Western Canada, apart from some possible effect on the total volume of the market. Moreover, a large segment of the Canadian market is free from duty through special treatment, as in the case of agriculture, or through drawback of duty permitted exporting industries. I do not believe that Canadian tariffs can materially improve the competitive position of petrochemicals produced in Alberta. Obviously the Canadian Tariff can have no direct bearing on the export of petrochemicals to the United States or to other foreign countries. I would like however to discuss the Canadian Tariff in relation to chemical industry generally in more detail a little later on.

In world export markets, particularly in the United States, Alberta chemicals must compete with similar products produced from similar raw materials and from crude oil. The availability of L.P.G.'s and other petroleum products in Alberta makes an export petrochemical industry possible, and the large petroleum reserves are a guarantee of a continued supply of raw materials over a long period. Nevertheless Alberta production must be sufficiently low in cost to overcome tariff barriers, transportation costs and to compete with large scale production both in the United States, Europe and Japan.

In the United States market tariffs are a formidable barrier, as they generally apply to manufactured products but admit raw materials either free of duty or with low duties. A petrochemical industry south of the Alberta border, using Alberta raw materials, would have no tariffs to overcome in the United States market. If raw material costs, south of the border, were approximately the same as in Alberta, a plant south of the border would have a substantial competitive advantage. It is thus again apparent, that if Alberta is to promote the petrochemical industry, it must provide the incentive of low raw material costs to offset other disadvantages.

The argument may be put forward that Alberta already has a large chemical industry despite the disadvantages referred to. I believe the answer is, that when the present petrochemical industries were established, petroleum products were in a preferred position which has since changed with the general surplus of petroleum products, with pipeline transportation and with new techniques. If the existing industries are to prosper and export, their competitive position will have to be improved.

It was stated earlier that a protective customs tariff on petrochemicals would provide little incentive to large scale consumption of L.P.G.'s in Alberta. At this point I would like to discuss tariff protection in relation to chemical industry in general, as the importance to Alberta of a further diversification of chemical industry is very great.

As you are doubtless aware, the Canadian Chemical Tariff is currently under study by the Tariff Board, and a great deal of work is being done and briefs are being submitted by the Chemical Industry. It will be some time before the Board's recommendations are made. Industry's views are by no means unanimous. The secondary chemical industry as, for example, synthetic fibres, plastics, pesticides and a wide range of other products seeks tariff protection from low cost imports, which reduce market volume and disrupt the price structure. The exporting chemical industries on the other hand fear reprisals which would affect their export markets.

Tariffs have a number of purposes and far reaching and sometimes unpredictable effects. In the first place, they provide the Federal Government with a source of income and are therefore a part of fiscal policy. For this reason tariffs are determined by the Department of Finance although administered by the Department of National Revenue. In the second place, they are a tool of economic policy, and it is this aspect of tariffs we are presently considering. Similar important factors of economic policy are exchange rates, taxation, royalties, transportation subsidies, quotas, and other forms of government intervention at all levels.

The Tariff generally assumes that all imports are subject to duty -- presumably for fiscal reasons -- and then proceeds to set up exemptions and make different rates of duties for different types of products. Exporting industries are permitted a 99% drawback on duty for products used in their manufacturing processes, and exemption from duty largely applies to imports for agricultural purposes and for the extractive industries. These are in the main the larger industries in Canada: for example, forest industries, mining and smelting, petroleum products and petrochemicals, one of the latter being synthetic rubber. A very large segment of the potential market is thus directly exempt from duties. A further complication is the fact that drawback of dumping duty is also permitted the exporting industries. As this situation is not generally understood I would like to enlarge upon it: assessment of a customs duty is based on fair market value in the country of origin. In other words, the price on which the duty is assessed is based not on the cost but on the fair market value in the country of origin. This, obviously, is an effort to make the tariff effective by avoiding false evaluations or distress prices. Dumping duties are the additional duties applied if the true market value is not represented by the purchase price of the goods. However, in common with ordinary duties, dumping duty does not apply to products used by exporting industries. This essentially means that chemical industry in Canada, supplying the exporting industries, must compete not only with the fair market price in the country of origin but must also face the dumping of surplus capacity at distress prices. The effects are far reaching and sometimes lead to more than one price for the same product within Canada: Soda ash, for example, sells at one price to suppliers for the domestic market and at another price to exporters. Ethylene glycol has three prices in the Canadian market -- the duty-free import price for exporters, a special tariff rate for plastics, and the full duty-paid price. If the Canadian manufacturer wishes to obtain the exporter's business he must meet the duty-free imported price, and frequently this means competing with dump or distress prices. This puts the Canadian manufacturer at the mercy of foreign exporters, who can dump when it suits them or withdraw from the market. This practice can also be used as a means of choking off the possible establishment of new industry in Canada to serve the Canadian exporting industries. It also provides subsidiaries of the United States or other foreign countries with a competitive weapon not available to Canadian companies. For example, a U.S. subsidiary operating in Canada can supply the Canadian domestic market from a relatively small plant and supply the Canadian exporting industries from existing sources in the United States or elsewhere. Where new demands from the exporting industries arise, these can be supplied from the United States; whereas the Canadian company must increase its capacity to do so and face possible dump prices from the United States to discourage Canadian expansion.

While a reasonable case can be made for drawback of ordinary duty, I believe the drawback of dumping duty as applied to products manufactured in Canada, and particularly chemicals, is an iniquitous measure giving foreign competition unfair advantages. Drawback of dumping duty actually defeats its own purpose by stifling possible Canadian expansion to supply a large segment of Canadian industry. Domestic production, competitive with imports through drawback of ordinary duty, provides a stable local source of supply at fair competitive prices and materially benefits the whole Canadian economy.

The question may well be asked: Why not export to the United States or other foreign consumers who would be permitted drawback of duties if the resultant products were re-exported? Unfortunately this turns out to be a one way street, in that exports of our primary industries are mainly used for further processing for local markets in the foreign countries.

I believe cancellation of drawback of dumping duty on chemicals made in Canada would do much to stimulate new chemical industry in Canada. I know of no better way of increasing productivity than by promoting industries which will use our natural resources thus creating wealth on all levels. Caustic soda and chlorine from Alberta salt and sulphuric acid from Alberta sulphur are supplying the industries of Western Canada and are building up the Alberta economy. More of this type of industry in Canada is urgently required, and I believe opportunities exist which are currently being thwarted by the threat of foreign competition taking advantage of drawback of dumping duty.

Other fiscal policies can also materially influence the economic climate. The exchange rate on our dollar directly affects the selling price in foreign markets, and the Canadian dollar at a discount promotes exports and constitutes a barrier against import. Royalties on natural resources are a main source of revenue to this Province, but they are also a direct tax reflected in production costs. Where the natural resources are further processed in the Province, the Provincial Government should promote their use by taking steps to bring about a price differential in favour of domestic use versus export. This might be done by a subsidy to manufacturers using the resources in Alberta. I believe the indirect benefits to the Province in capital investment, employment, etc. would more than offset any revenue losses. I believe the Dominion Bureau of Statistics figure for gross sales value of chemical and allied products in Alberta will be about $80,000,000 for 1961. Apart from capital charges, this represents expenditures mainly in Alberta for labour, supplies, raw materials, etc. If we assume the export price of natural gas is 15¢ per thousand cubic feet, this is equivalent to the gross sales value of 533 billion cubic feet of natural gas.

Federal tax relief for exporting industries can also be helpful, but, obviously, should be slanted at manufacturing industries rather than at export of natural resources if the greatest gain to the community is to be realized.

I have always found it difficult to understand why municipal taxation in Alberta should be much higher than in other areas, more particularly in Eastern Canada. Such taxes are a direct cost against production. Recognition of the contribution being made by domestic industry surely justifies adjustment of this tax rate to reasonable levels. Other costs must also be kept down. Unreasonable wage demands which increase costs simply reduce the export markets that can be reached and this minimizes employment.

What comes out of all this discussion?

I believe the Alberta position can be summed up as follows: Canadian tariff protection can have little effect on Alberta production of petrochemicals from L.P.G.'s, as these must be sold in the main outside of Alberta and outside of Canada.

L.P.G.'s no longer possess a unique position as a source of petrochemicals, such as ethylene, propylene, butadiene, etc. which, in turn, are building blocks for chemical industry.

L.P.G.'s will have to be priced to permit petrochemicals produced from them in Alberta to be sold in export markets. This essentially means that the price of L.P.G.'s for use by Alberta industry must be more favourable than the export price.

The same basic principle applies to other Alberta natural resources. For example, the use of natural gas to produce fertilizers, or salt and sulphur to produce primary chemicals, brings much greater benefits to the Alberta economy than the export of the gas or the salt or sulphur, and recognition of this should be reflected in the cost to the Alberta industries.

Federal tax incentives for export, more favourable municipal taxation and more favourable transportation costs are all important in promoting the further development of Alberta's chemical industry.

Drawback of dumping duty poses a serious threat to the establishment of new industries, and removal of this threat would stimulate the further development of the Province's chemical industry.

You may well say that such proposals as I have made tend towards a 'planned economy'. I prefer to think that the development of a better economic climate should be regarded as a cooperative endeavour by Government, Industry and Labour, looking toward the greatest benefit to the Alberta economy from Alberta's wealth and natural resources.

There already exists a large measure of planned economy in Canada: prohibition of export of pulp wood has been a major factor in the development of the pulp and paper industry; and Federal and Provincial policies largely regulate the Alberta petroleum industry. Whether we like it or not, Canada must compete with planned economies in other areas. I have just returned from a trip to Europe and it is very evident that the resurgence of European industry since the war has been a carefully planned economic effort backed by Government, Industry and Labour. In the United States the same trend is evident.

If, as a result of economic pressures, a North American common market comes about, Alberta chemical industry should be in a favourable position to take advantage of the enlarged markets which would become available. However, political developments of this sort are notoriously uncertain, and Alberta should face up to its own problems and improve the economic climate for domestic industry.

The views I have put forward are my own and result from experience obtained in promoting and establishing chemical industry in Canada. It has been my particular good fortune to have been able to influence and participate in chemical developments in Alberta. I am confident that a greater chemical industry will eventually evolve in this Province, but I am also aware of the difficulties and the necessity for a hard-headed practical approach as against wishful thinking.

DISCUSSION

Mr. J. E. Oberholtzer, Department of Industry and Development, Edmonton, Alberta: On behalf of those who were inquiring regarding the drawback on dumping duties, that Dr. Donald had mentioned earlier, we ask Dr. Donald if he would explain.

Dr. J. R. Donald, J.T.Donald Limited, Montreal, Quebec: I mentioned soda ash. Metallurgical companies are one of the largest users of soda ash in Canada and they export the majority of their production. To the degree that they export their products they pay no duty on the soda ash for use in their manufacture of the exported material. Not only do they not pay any duty but they may bring it in at any price that happens to come along. This is no criticism. It is just an example of what can take place. If some manufacturer in Britain or in France or anywhere else gets a big inventory of soda ash and wants to sell it, they can cut the price and send it over to Canada to one of the exporting industries; and this they can do without any penalties.

The Canadian producer of soda ash has a protective tariff, but the tariff obviously only applies to consumers in Canada who supply the Canadian market: e.g. the glass companies. In the case of the glass companies, some manufacturers in Europe may want to dump soda ash into Canada, and this they can do, but the glass companies must pay the regular duty on the imported soda ash and also dumping duty. Canadian producers of soda ash thus have protection from foreign competition in supplying soda ash to Canadian glass producers.

The whole point is that Canadian producers of soda ash, as an example, have a measure of tariff protection covering some part of their potential sales, but on other parts, they are dependent on whether their customers are selling in the Canadian market or in the Canadian export market. The result is that the Canadian producer of soda ash never knows where he stands in relation to foreign competition.

ALBERTA'S STAKE IN CANADA'S TRADE POLICY

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Dr. Armstrong was born in Nanton, Alberta. He obtained Arts and Commerce degrees at the University of Alberta and a Ph.D. in Economics at McGill University, with one year post-graduate study at the University of Manchester. Dr. Armstrong is currently Director of the School of Commerce, McGill University, a frequent commentator on radio and television for the Canadian Broadcasting Corporation, and a private business consultant. Dr. Armstrong has prepared submissions and acted as an expert witness for the Gordon Commission, the Borden Commission, the Royal Commission on the Revision of the Financial Terms of Union between Newfoundland and Canada, and is currently serving as an adviser to the Royal Commission on Transportation. He has recently completed a study of the effect on Canadian-American relations of the corporate practices and policies of U.S. firms operating in Canada. In addition, he has acted as a consultant to all three levels of government, to trade associations, and to a large number of individual firms.

We Canadians have never been known for our eagerness to face facts or anticipate problems. This has certainly been true with regard to our position on international trade: to the point where it is not always apparent what Canadian trade policy is and it is almost never apparent where it is going. However, our practice of drifting and dreaming, and of settling every little problem on the basis of short run political expediency is just not good enough. The changes which are now taking place in the world's trading arrangements are presenting us with a trade problem which is becoming increasingly difficult to ignore. The treaty of Rome, signed on the 25th of March, 1957, established a common market in Europe which has steadily gathered momentum. Greece has joined as an associate member, Britain, it appears, is about to join, and in all likelihood she will be followed by a number of other countries. Inspired by the success of the European Common Market, plans are afoot for common market arrangements in Central and South America, Eastern Europe and Africa. Finally, President Kennedy has announced a new trade programme designed to lead his country and the free world towards freer trade. These events simply compel us to examine our own trade policy.

Now what is going on in Europe or in America, or anywhere else, is of concern to us only if we are resolved not to withdraw into a protective, isolationist shell. The very first thing to settle, therefore, is whether international trade is, like motherhood and the chamber of commerce, a good thing, or whether it is more properly classified with Sunday sports and other sins, as something to be ruthlessly suppressed.

There are many people who hold to the view that international trade is a bad thing and that Canada should restrict imports. We have been told repeatedly that imports (especially from low wage countries) cause unemployment among Canadians. It has been alleged that international trade reduces our standard of living, robs us of our self reliance, reduces our autonomy, makes us weak in time of war and reduces our Canadian togetherness by forcing us to hobnob with foreigners - some of whom are known communists and fellow travelers.

Now if these charges are true, then surely we would be well advised to simply pass a law (known in the economics profession as a high tariff) which would prevent international trade from taking place.

Of course, if international trade is a bad thing, it must follow that inter-regional trade is also. If we accept the anti-trade gospel we must prohibit trade between provinces and cities, indeed if we are to be pure, we must pass a law preventing any interchange of goods or services among individuals. Only thus will we insure that those who survive are fully employed, self reliant, autonomous, and as strong in time of war as in time of peace. In fact the survivors would be able to achieve the self reliant, autonomous, fully employed standard of living, and of loving, of a hermaphroditic earth worm.

Of course, the stupidity of such anti-trading legislation would be so self evident that the law would be harder to enforce than prohibition. As soon as our backs were turned boys and girls would be slipping off to form free trade associations called families. Families would soon find it convenient to form tribal free trade areas, tribes would unite into provinces, provinces into countries and every now and then countries would be moved by the logic and advantages of trade to form supra-national trading areas. Of course, the forces of tribalism, provincialism, and nationalism, will tend to inhibit progress towards freer trade.

We trade among individuals as we trade among states, to permit specialization of labour and equipment, to take advantage of economies of scale, to allow each family. area, or country to exploit more fully the natural advantages which it may have by virtue of rich natural resources, skills, know-how, or accumulated capital and to permit individuals to satisfy their wants more fully than they could if left to depend on their own resources.

Believe me, there is a much more complicated way of demonstrating the advantages of the free international exchange of goods and services. I think we may safely conclude without further elaboration, however, that more international trade will be better for Canada (and especially for Alberta) than less.

Now I cannot stress too strongly the importance which I attach to the future course of Canadian trade policy. Because of efficiencies introduced by the economies of large scale and of increased competition a large market area appears to be more efficient than a small one. The world shows every sign of organizing itself into larger more efficient market areas. If we try to go against this trend - if we become more protectionist and isolationist with our very limited market - Canada might well find itself with the lowest standard of living of any country in the western world.

I invite you to think about this proposition for a moment. One of the main pillars of Canadian growth has been our population explosion and this in turn can be largely attributed to immigration. Many of the new Canadians were pushed out of their homelands by the desire to escape from the battlefields of Europe. They have been drawn to Canada by our standard of living, second only to that of the United States which imposed rather stricter immigration laws.

The introduction of the ICBM means that now Canada rather than Europe lies directly in the path of war between the two great powers. If our standard of living drops below that of Europe, does anyone seriously believe we can attract population? We will do well to hold the population we have!

If trade is so important how do we encourage it? It seems to me that there are two ways of going about it. On the one hand we can advocate the gradual removal of tariffs on a multilateral basis through some agency such as G.A.T.T. We can try to promote our association with a limited free trade area such as Europe, or the United States, Japan or the West Indies. On the other hand, either of these two routes could end up at the same place. For, as a member of a free trade area, there is nothing to prevent us from advocating the gradual elimination of tariffs among free trade areas. The first step in joining a free trade area may be more important to Canada than the second. I suspect that the additional gains from trade to be realized by further extending the area of free trade declines as the extent of the market is broadened. Increasing our available market from, say 10 to 100 million, is much more important I suspect, than increasing a market from 100 to 200 million.

I believe I am right in saying that many, if not most, economists support the second approach: that is, the gradual reduction of tariffs on a completely multilateral basis. However, there is a practical difficulty with the multilateral approach. It arises because most international trade means international competition, and competition is a cruel and painful process.

When one competitor drives another into bankruptcy, the employees, the employer and some innocent bystanders associated with the bankrupt firm are injured. This injury is localized and can be easily organized into a political protest. The benefit which is achieved through the process of competition - that is to say the better or cheaper product - is spread thinly over the whole consuming area. Even though in total, the benefits of competition may exceed the injuries, which I believe they do in most cases, the benefits are so thinly spread that they cannot form the basis for effective political action.

Thus it is that the intellectual leaders of a country, who are in a position to look at total benefits and total costs of trade and competition, tend to frame policies of freer trade, but when it comes down to cases, the political pressure which is generated to remove foreign competition, drives each country to place more and more restrictions on imports.

If you examine our own trade policy in the last few years, I think you will find that we preach free trade for other countries; that is to say, we implore other countries, on the grounds of sound economics, to let in our products free, but whenever imports begin to hurt a Canadian manufacturer or, God help us, a Canadian farmer, we will take measures to reduce foreign competition.

The injuries inflicted by competition will usually develop anti-trade pressures whether the trade is intranational or international trade. However, with a few exceptions we are prepared to accept the discipline of competition within a country; indeed we encourage it even if it results in a company in Toronto forcing the bankruptcy of a company in Halifax. We are less inclined to accept the discipline of competition if there is some danger that a Toronto company will be forced into bankruptcy because of the competition of companies in, say, Germany or Japan. I suggest it is easier to win acceptance of the sometimes painful discipline of competition in a more limited market than it is for a market covering the whole world.

There is also a more practical consideration. Countries within a free trade area will tend to become more highly interdependent over time, with the result that each individual member of the club can less afford to apply trade restrictions against a fellow member. Discipline - by which I mean the acceptance of competition and of market decisions - within a limited common market is likely to be tighter than it will be for a world-wide common market. This is likely to be so until we develop a much more enlightened electorate than we now have.

Another major advantage of a common market arrangement for Canada is that, for that market at least, it would remove the bias in the tariffs of other countries which prevents us from fully processing our own raw materials.

Tariffs everywhere are structured against manufacturing or processing. There are two reasons for this. In the first place, competition in the production of raw materials is less pervasive than is competition in the production of more highly manufactured goods. One can build a plant to manufacture copper wire anywhere in the world but there is no point in digging a copper mine anywhere but over a copper deposit. As a result, there are more countries interested in manufacturing wire than producing ore and more countries are therefore inclined to restrict foreign competition with regard to wire. It is not surprising, therefore, that tariffs on wire are almost always higher than tariffs on ore.

This, if you like, is the rational basis for the tariff against manufacturing. The irrational basis stems from the feeling that secondary manufacturing is some sort of index of national progress. It appears to be a greater source of national pride to have produced a suit of underwear than a ton of pulp, a saucepan is a greater cause for rejoicing than a bushel of wheat, and our national awareness is more deeply stirred by reading the "Made in Canada" label on a pair of 12 gauge 60 denier nylon hose than on a thousand board feet of knotty pine.

The double presumption, first, that secondary manufacturing is a good thing and, second, that Canada's entry into a free trade area would eliminate manufacturing in Canada, is very deeply embedded in Canadian folklore and explains much of the political opposition to trade. The idea warrants our careful consideration.

It has often been argued that secondary manufacturing in Canada is an inefficient, high cost activity which cannot survive free international competition. I had heard this statement so often that I had always assumed it to be true and had come to the conclusion that greater emphasis on trade would shift employment in Canada from textile mills to smelters. This did not worry me particularly since the shifts in the labour force which I foresaw were not large and since I expected them to enable us to increase our productivity, our wages and our standard of living. Recently, however, I have come to question the premise that freer trade would significantly reduce secondary manufacturing in Canada.

A common market would benefit Canadian secondary manufacturing in two ways. First of all, it would offer Canadian industry free access to a larger market. Just because a particular Canadian plant, scaled to the present size of the Canadian market might have costs which are too high to enable it to compete in world markets does not prove that it would not be competitive if it could be guaranteed access to a market which was, say, ten times as big. A number of businessmen that I have talked to have assured me that if they could have guaranteed free access to either the European or the United States market, they would make out just fine.

But the access must be guaranteed. Not long ago I had occasion to ask why a certain refining operation was built in the United States when, according to my information, the product could have been produced more cheaply in Canada and exported to the United States, even over the U.S. tariff. The person who made the decision told me that the plant was located in the United States because he feared the U.S. tariff would go up. A tariff increase in the United States could have destroyed the value of the investment, and the company officers reasoned that it was better to settle for slightly lower profits and avoid the risk of a large capital loss. Yet this was a processing plant which, on purely economic grounds, should have been located in Canada.

High costs of manufacturing in Canada may not all be blamed on the small size of the Canadian economy. A recent study made in the United States indicates that for the majority of manufacturing industries, small plants have been able not only to flourish but to increase their share of the market.

I must conclude from this that in some instances at least, manufacturing costs in Canada, which are high relative to the United States, may be attributable less to the limited size of the Canadian market than to the lack of competition in Canada. Industry which has grown up behind a protective tariff wall should, in theory, be working towards the day when it can exist and flourish after the wall has been removed. Instead all too many industries become more and more dependent on the shelter afforded by tariff protection.

Whether our manufacturing industry is suffering from an inability to achieve economies of scale or a failure to benefit from the economies of comprtition the prescription, it seems to me, is the same: merge the Canadian economy with a larger trading area which will afford, at the same time, advantages of scale and the advantages of more effective competition.

There is one other reason why I like the idea of a common market arrangement and that is that a re-drafting of tariff boundaries - which is what the formation of a common market amounts to - is an enormous spur to business. For this and other reasons, I think we shall see a period of unprecedented growth and prosperity in Europe. I know that there are economists who have forecast a slowing down in the European rate of growth over the next ten years. However, I most emphatically disagree. The formation of a common market in Europe is, I think, a more important, a more far reaching innovation than the introduction of the railway or the opening up of the American West. Indeed the analogy with the North American frontier is, I think, striking. It is perhaps cruel for a son of Alberta and the son of an Alberta pioneer to say this, but the fact is that the opening up of the American West produced so much investment opportunity simply because the development of the new territory was not a frightfully difficult entrepreneurial job. The frontiersman did not have to worry about untried products or unproven production methods, he needed only imitate the economic activity which he or his father had carried out in the area from which he emigrated. There is no shortage of people in this world who can imitate, there are not many who can innovate.

The European common market is equivalent to a frontier. Its development presents the European businessman with the opportunity to imitate the U.S. production techniques which have been developed and proven to be profitable for a market of that size. As income shoots up it will also be possible to market the luxury and semi-luxury goods already successfully marketed in the affluent United States.

As you can see from the foregoing, I think there is an excellent case to be made for Canada joining a common market.

If Canada were now to become associated with the European Common Market, under article 238 of the Treaty of Rome, I am confident that Canadian industry - including some Canadian secondary manufacturing industry - could do very well. You will recall what happened under the spur of the British preferential tariff, which was a watered-down kind of common market. Canada became the doorway through which many American, and Canadian, controlled firms gained access to Commonwealth markets. I am reasonably sure that the same thing would happen today for the European market. Some of our Canadian plants are miniatures of their U.S. counterparts. They have the U.S. know-how and are in a position to expand quickly to take advantage of the scale offered by the European market. Guaranteed free access to the common market would also cause a boom in our resource-based industries.

If we don't join Europe we will suffer a slight deterioration in our competitive position in those European markets in which we must compete with other sources of supply within the Common Market. This disadvantage will not be too serious and I expect it will be at least partially offset by the increased growth of European markets.

I have been told by some leaders in the chemical industry that joining Europe would cause an upheaval in the industry (an upheaval, by the way, is always in itself good for business), but that with guaranteed free access to the European market we could, by specializing in a narrower range of products, get our costs down and our volume up.

All these references to joining the European Common Market are quite academic unless there is some chance that we can get into the club.

In order to properly assess our prospects for membership, we need to have a little clearer idea of what the Common Market is. It is much more than a marketing arrangement; it is a vision. It is a vision of grandeur. It is a vision which is nurtured consciously and unconsciously by rivalry with both the United States and Russia. I am convinced that this rivalry would in fact make it possible for us to obtain entry into the common market if we chose to do so. We are, after all, the prime satellite of the United States. What a prize we would be to the European Community.

From all this you may have concluded that I am going to advocate joining the European Common Market. Well, I'm not. I do advocate that we give the matter our serious consideration. I think we should be prepared to join Europe if we cannot work out satisfactory arrangements elsewhere. But I think we should try to work our arrangements elsewhere and I think we should start with the United States.

At the present time we are an economic dependency or, if you like, an economic satellite of the United States. Now I am not trying to stir up anti-American feeling, I am stating a simple fact. If we are determined to operate with a market of 18 million people, we are not going to have much economic independence unless we are prepared to take a sharp decline in our standard of living. We are just lucky that we are sharing this continent with the United States and not Russia. However, the fact remains that economically we are very much in bed with the United States and we are in constant danger, not of being seduced, but of being ignored.

As you all know, we are now heavily in debt to the United States and we will be required to earn an enormous surplus on current account every year in order to obtain the foreign exchange with which to service and repatriate our past borrowing. How hard we shall have to work to carry this burden depends very largely on our ease of access to U.S. and other foreign markets.

Many of the text books on trade are written as though trade took place only between countries of roughly equal size, with about equal power to inflict injury on each other. This is not the case with Canada - U.S. trade. We are in no position to use tariffs in a retaliatory way. The United States is.

For the most part Canadians have to sell their products at a world or at a U.S. price. If the United States, or the world in general, puts a tariff on our products, that tariff must simply be deducted from the revenue which our exports receive. By contrast, if we place a tariff on the goods which we import, that tariff is not usually deducted from the revenue of the foreign exporter, it is simply added to the price which Canadian customers have to pay.

Nor are we usually in any better position as consumers if a manufacturer decides to take advantage of the Canadian tariff to manufacture in Canada. It seems to be an invariable rule that the cost of manufacture of a protected item is equal to the foreign price plus the amount of the Canadian tariff.

What Canada needs, and what Canada needs very badly, is free access to foreign markets for those goods which we can produce efficiently. A common market is one solution, free access to the United States for some of our more highly processed materials is another.

In negotiating with the United States, however, let us be wary of the cross-the-board tariff cut. This it seems to me is not what we need. If we did get trapped into lowering our tariffs by 50 per cent, say, while the United States did the same, we might damage some sectors of our economy without at the same time obtaining the offsetting advantage of guaranteed free access to the enlarged markets which we need. I am just horrified to hear a United States Senator propose that reciprocal trade cuts might be made for a one year trial basis. Nothing could be less suited to our needs.

What has all this got to do with Alberta and with our Petrochemical Industry. For the foreseeable future it seems to me that Alberta will have a resource based economy. Within a tariff protected market, manufacturing and processing not tied specifically to a natural resource will tend to gravitate to the centre of that market, for it is there that transportation charges are minimized. This means that so long as Canada is surrounded by a tariff wall, Ontario and Quebec will continue to attract most of Canada's secondary manufacturing and there is very little that any other province can do about it . . . except to press for a more liberal trade policy. The more highly protectionist is our trade policy, the more boots and shoes will be produced in Ontario and Quebec and the smaller will be the output of petrochemicals in Alberta. I believe that if we adopt a commercial policy in Canada which emphasizes international trade, Alberta and Canada will benefit. If we try to go it alone, Canada, but especially Alberta, will suffer.

DISCUSSION

Mr. R. C. Sykes, Polymer Corporation, Sarnia, Ontario: I would like to ask if Dr. Armstrong would comment on the experiment in limited free trade in the farm machinery industry between Canada and the United States. I think there has been some concern that this experiment has not entirely worked to the favour of the farm machinery industry in Canada.

Dr. D. E. Armstrong, McGill University, Montreal, Quebec: You are quite right. It hasn't worked too well. The problem is of course that there are really only two companies in Canada. I think that part of our difficulty is associated with the difficulty in one of those companies. You just have to have one of these companies decide to put a plant here vs. there and this statistically would produce the results you referred to.

The example I think is not a very good one, because agricultural implements are not a resource based kind of industry. The economic force of drawing a tariff boundary around North America will tend to collect that kind of industry in Chicago, not in Canada. This is why I have not advocated a common market with the United States. There are two reasons for this. The first reason is that we are on the tariff boundary, if you like, of North America. I think that a lot of secondary manufacturing would automatically gravitate to the centre of the North American continent, which does not really include Canada. I think the farm implement just shows that this is the drawing force. This is exactly the same reason why secondary manufacturing tends to be accumulated in Ontario and Quebec. Another reason I am not advocating a common market with the United States is that trade policy right now in the west is gravitating towards a common market in the North American community. Now I think that for the long term prospects of world peace this would be an undesirable development. The North American free trade area would be a white, rich man's club. I can visualize Russia and the United States growing together and uniting against China. I think if we lay out our trade policy in such a way as to accelerate the pooling of this world's population around a color barrier we've got a very explosive situation.

Now I'm not running for office and so I can say what comes into my head. The common market which would make most sense and which can start out on a very limited basis is one of Japan and the West Indies. This is a multi-racial common market and on a limited basis makes a lot of sense. Various references have been made to our problem of selling in and around the world. Just take one example I know something about. Japan has a market for about 2 million tons of the sulfur that we are producing so much of in Alberta. It costs them something like $50 per ton to produce. Now why aren't they buying our sulfur? They are not buying our sulfur because we are already flooding the Japanese market with cheap Canadian goods. We are already selling to Japan about 50% to twice as much as we buy. Their currency problem is such that they cannot - will not - buy our sulfur until we buy some more from them. Now it would be a fairly simple thing to prove the enormous advantage that would be gained by making a deal with Japan on some of this type of product. But we've got to be prepared to make concessions on the other side. We can't just sell without expecting to buy. Trade doesn't work that way.

Mr. G. R. Heffernan, Premier Steel Mills Ltd., Edmonton, Alberta: I would like to ask Dr. Armstrong, using another example, his opinion on the iron and steel industry in Canada which was built up under fairly substantial protection without raw materials existing in Canada at the time that it started. Today the base price of steel in Hamilton is $5.35 per 100 lbs. Across the lake in the U.S. the price is $5.65 per 100 lbs. I don't think that there is any question but that the iron and steel industry in Canada would not have grown without protection. I'd like to have you comment on this. Is this a bad thing that it has grown? It seems to me that it's a very good thing. We have lower steel costs now in Canada than exist in the U.S. But this would have been absolutely impossible in the face of U.S. competition in the early days.

Dr. D. E. Armstrong: The economist recognizes two arguments for protection (tariff). First, infant industry argument. I think steel is a very good case in point. If, looking at our resources and our abilities, we think that we can develop an industry in Canada which in the long run will stand on its own feet and get its cost down so that it can be competitive in the world, then there is every justification for putting a temporary tariff to foster the growth of that industry. However, I think steel is an example which proves my case and not the opposite case. This happened in steel. Why, I don't know. Energy of the steel companies? For some reason or other, the steel companies are alive in Canada. A lot of innovations were made in the steel industry in Canada long before they were made in the United States. Now you take a look at some other industries that were set up in Canada under a supposedly temporary tariff. The same thing hasn't happened. A lot of these industries shouldn't have been established in Canada in the first place. Under our tariff we have succeeded in setting up a lot of assembling operations in Canada.

When I was working on this "Canadian American Study" that the Chairman referred to earlier, I went to one of the particularly bad actors in Canada. This company has a wonderful public image in Canada. It assembles parts and makes a little machine which it sells. It only has to add 25% of the value to get protection. The price of the product is 25% more in Canada than in the U.S. This company in terms of increasing the vigor of Canada - conducting research, etc. - is a very bad actor, with rather poor performance.

The tariff in Canada established in that case an industry which has no future in Canada. All that we can do is persuade the Americans to send up a bunch of pieces, which is an awful nuisance. They have to be layed out on another assembly line and fitted back together and the process of packing and unpacking adds 25% to the cost to Canada. But the packing and unpacking is done by Canadians. We'd be better off to pension off the workers in that plant and buy this product from the U.S. So what I object to, is that the tariff policy which made a lot of sense in some cases was done without any long run consideration at all. We simply wanted industry in Canada. We didn't investigate whether this particular industry could flourish in Canada. I think Dr. Donald put the point very well. We assume a tariff on everything then made exceptions. We shouldn't have done that. We should have looked at what kind of industries can flourish in Canada. We should have protected them, and let them know that the tariff would be a shrinking protection. Of course, I'm assuming everybody else is going to be a good boy and play by the same set of rules. If we play by this set of rules and other countries don't, then we'd inflict great injury on ourselves. Dr. Donald referred to the dumping problem. This is a very real problem for a kind of a marginal country like Canada. This is why I tend to favor the limited common market approach rather than the general multilateral approach because then you can tie the hands of your trading partner a little more securely and get the guaranteed access to the markets that you need.

SUMMATION OF SYMPOSIUM

J. E. Oberholtzer
Deputy Minister, Department of Industry and Development

The task of summarizing this very fine symposium is not an easy one. The speakers were particularly interesting and, having a leaning towards personal statistics, I was intrigued at the distribution of the speakers and committee personnel. These were as follows: 10 native born Albertans, 2 from elsewhere in Western Canada, 2 from Ontario, 2 from Quebec, specifically Montreal, 2 from the United States, 4 from Europe and 1 from the West Indies.

May I give some general impressions from the papers themselves.

1. There was a clear indication of the ample resources of raw material supplies with specific figures to which you can refer for several years.

2. A clear statement of the government's background thinking, attitudes, and policies was outlined.

3. A description was given of the ever-widening of world markets which is going on steadily but with growing competition in those same areas.

4. An ever increasing variety of products and processes was described, inferring that there is some room for maneuvering either for large operations or small operations. There are opportunities for opportunists to grasp a certain set of situations and move into a field even though there is competition. At the same time there is a strong feeling of the built-in danger of obsolescence. The rapidly changing processes and the rapidly changing products carry an inherent danger of obsolescence. Still, a versatility of operations and an ability to change without too great a damage to your capital structure may be considered a key note here.

With relation to local markets, rates of growth should be examined carefully. One point was not thoroughly covered; there was a consideration of large plants and small plants, with not too much in between. What is the optimum size of plant for lowest unit cost in relation to these same local markets, realizing that this cost is varying from year to year and from circumstance to circumstance?

Throughout the whole proceedings it is safe to say that there was a theme of optimism - not glory-eyed optimism, but a sincere optimism, with a practical and realistic tone to it.

With respect to the sequence of the program we may compare the symposium to a company's annual report. The first pages give a report of production, new processes used, expansion that has taken place during the year's operations, but the key for the final reckoning is on the pages signed by the auditors. This is the profit and loss statement where the economies come into play. That is what we've had this afternoon. The economic aspects must be faced.

We have had some sobering thoughts on transportation costs but with some hopeful notes as to new methods and procedures to meet the situation. There was a recognition of serious competition existing close at hand in the United States and elsewhere, but still an expression of confidence and hope in the ability to adjust. Some consideration was given the total economic scene, the effects of the world changing markets, and the effects of population concentration.

Now may I offer some comments on the symposium and its arrangements. Particularly of interest is the high registration of approximately 200, with a high continuous attendance. So often even in a 2-day gathering the attendance tends to fall off but this has not been so in this case. There was a good balance to the program. I'm waxing enthusiastic I know, but I am repeating some of the comments that have been passed on already.

The speakers should be complimented on the high calibre of their papers and their presentations. This is a credit to the committee for selection, and to the companies and individuals providing the material.

Questions were somewhat few in number. This may be disappointing but not unexpected. When a paper of depth and comprehension is presented it is difficult for the mind to move fast enough for a question to be formed as soon as the paper is finished. This is a credit to the thoroughness of preparation of the papers.

The undertaking of this symposium has been a community of effort and a community of interest in which participated the Chemical Institute of Canada, Edmonton section, the University, the Research Council of Alberta, the Provincial Government, particularly the Department of Industry and Development, and through the auditorium, the people of Alberta. Congratulations are extended to all the participants in making the arrangements. The same community of interest will be evident at the 62nd Annual Conference of the Chemical Institute of Canada in Edmonton on May 26th to 30th, and it is hoped that most of you will attend.

Finally, a few suggestions.

1. Review and consider your current impressions of what you have heard during the past two days.

2. Carefully and thoroughly study the papers that you will receive in the not too distant future. Check them, challenge them, see if they add up, and hopefully from our point of view, lead your company to some further contemplation of Alberta as a location for a petrochemical or chemical development. We

hope you come back with a project in your mind and a gleam in your eye. If you do come back, this whole group - this community of interest and effort will be on hand to assist in every way possible.

We hope that this symposium has been timely, timely in relation to economic, geographic and political developments.

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