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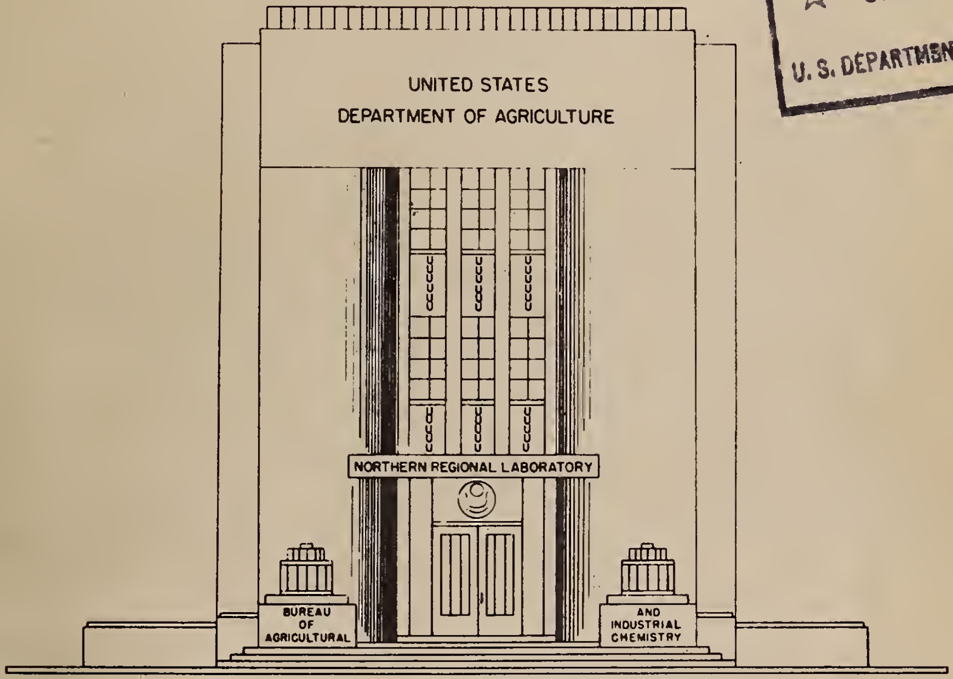
ALCOHOL FROM AGRICULTURAL COMMODITIES



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FOREWORD

Several agencies of the Department of Agriculture have cooperated in a program of post-war planning under the general direction of the Secretary and an Inter-bureau Committee. The work in marketing consisted of a number of projects, one of which was Post-War Readjustments in Processing and Marketing Facilities and Methods. This report, one of several which were prepared as part of the latter project, was prepared in February 1944 by P. Burke Jacobs, Industrial Analyst, Northern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry. Subsequent minor statistical and text revisions were made in August 1944, January 1945, and May 1945, because of continuing changes in the industry.

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ALCOHOL FROM AGRICULTURAL COMMODITIES

A Survey of Production, Utilization, and Industrial Aspects

Introduction

Ethyl (or "grain") alcohol is one of the most important chemical commodities. It is derived from many sources, by diverse methods. Due to the manifold uses and applications in industry and commerce, alcohol is marketed in a great many forms, ranging from pure and practically anhydrous alcohol to solutions or mixtures containing various (and often relatively small) percentages of spirit.

The manifold applications can, however, be differentiated into two general fields: (a) industrial chemical, physical, pharmaceutical, and food uses, and (b) beverage uses. Four practically separate industries have been evolved to supply these requirements, three of these normally being wholly beverage producers. However, only two of the four industries actually produce alcohol by distillation, in usual practice. These general production industries are distinctly separated legally. In actuality there is a common basic relationship as to methods of production and raw material supply in the two industries using distillation methods, while a complex interlinking exists on other production and use aspects. Consequently, any study of alcohol as a commodity must include both non-beverage and beverage branches of production, and in order to visualize post-war conditions, the present organization, capacity, and methods used in both distillation branches of the industry must be understood.

Concerning the production of alcohol in concentrated form, a clear-cut division of the general alcohol-distillation industry can be made. Practically all alcohol produced for chemical, physical, or manufacturing uses is originally recovered at concentrations of 95 percent by volume, or higher, in a relatively pure state, regardless of the subsequent use, or form in which sold. All alcohol produced at such concentration (and degree of purity) is known as "industrial alcohol," regardless of source material, and is produced under and controlled by a specific code of regulations. Conversely, alcohol recovered by distillation for use only as a beverage (distilled spirits) is marketed in concentrations not exceeding 80 percent by volume, in a semi-purified state only, under distinctly separate legal regulations, and the source material is specifically limited.

The two separate industries producing alcohol by distillation are legally known as the "industrial alcohol industry" and the "distilled spirits industry." While alcohol produced by one industry may be transferred subsequently to the other industry for use, this constitutes a secondary and independent proceeding, and the basic production is statistically accredited to the original producer industry.

Production and Consumption of Industrial Alcohol

The following discussion and analysis is primarily concerned with the Industrial Alcohol Industry, which is the more significant one for the present purpose. However, pertinent aspects of the beverage alcohol industry are also discussed, where applicable.

Previous to World War II, the normal consumption of industrial alcohol in various industrial channels for chemical, physical, or manufacturing use (up to 1939) was about 100 million wine gallons (190 proof) annually, either as pure alcohol, specially denatured alcohol, or completely denatured alcohol. Some additional quantities (±13 million gallons) of industrial alcohol were produced and used annually in recent years, but such additional consumption consisted principally of pure alcohol which found relatively nonindustrial uses both as tax-free and tax-paid alcohol (much of which subsequently was transferred to and used in the beverage industry for blending of spirituous liquors), and can be considered as representing a special type of industrial alcohol, for purposes of this discussion, although statistically included in such production.

Under the industrial alcohol act of 1906, alcohol used for industrial purposes and not for internal use (principally as denatured alcohol) is tax-free. However, pure alcohol also is produced by the industrial alcohol industry, and such alcohol may be sold as tax-free or tax-paid, depending upon use. Thus, pure alcohol for hospital, scientific, or Government use is tax-free, while pure alcohol for making foods, beverages, flavorings or pharmaceuticals for internal use is taxed. In certain uses a portion of the original tax paid is refunded.[a]

While the amount of alcohol annually used in industry fluctuated with trade activity previous to the present war, there was no significant opening or development of new or enlarged markets over a great many years. Occasional new or increased consumption in specific lines usually represented less than 10 percent of the normal production. Prices remained at low levels, consistent with raw material costs. It is doubtful if a lowering of prices would have stimulated any significant new markets, (except motor fuel, as discussed hereinafter), since ethyl alcohol usually was the cheapest material in its field. When the present war began abroad, the industrial demand for alcohol in the United States began to rise, partly for direct export purposes but principally as a result of expanded manufacturing to fill the requirements of warring nations. With the entrance of the United States into the war, the alcohol requirements for munitions, synthetic rubber, and other war uses, as well as the needs of allied nations under lend-lease agreements, raised industrial alcohol requirements to unprecedented figures. Production of industrial alcohol reached 365 million wine gallons in the fiscal year ending June 1943, and 519 million gallons in the fiscal year 1944. It may amount to 578 million gallons for the

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[a] In pharmaceutical use, for example, an original tax of $9.00 per proof gallon is imposed, but a drawback of $6.00 a proof gallon is allowed. The original tax of $9.00 per proof gallon applies on all pure alcohol subsequently used for beverage purposes as a blending agent, et cetera.

fiscal year 1945[a], (or 565 for the 1944 calendar year), and 580 million in the calendar year 1945, as new plants reach maximum operation. Significantly, annual tax-free alcohol withdrawals (principally for the use of the U. S. Government) increased from a pre-war nominal and usual 1.0 million gallons or less to 25.2 million in 1942, and 67.0 million in the fiscal year 1944, largely representing munitions manufacture and lend-lease. b/

Since the existing industrial alcohol industry did not have the capacity for producing the amounts needed to meet the unprecedented demands, it was necessary in 1942 (October 8) to secure the aid of the distilled spirits industry, stop all beverage alcohol production from grain, and set this industry entirely to industrial alcohol production insofar as it was equipped for such effort. A number of temporary arrangements were made, and existing laws and regulations were greatly modified to permit the accomplishment of the desired purpose. It is significant that an apparent increase of alcohol production of about 500 percent has been achieved by perhaps a 40 percent increase in installed capacity, through the brigading of the industries. This apparent miracle of production was aided by the fact that much unutilized or inactive capacity was available. While production goals have been met by this expedient, the present situation cannot be rated as an entire economic success, and it might not be desirable to continue the arrangement in entirety under normal production status, without further changes. Furthermore, recourse to this expedient has caused a shortage of beverage alcohol in all forms, with depletions of stocks which will take several years' operation to replace. a/

The production and use of industrial alcohol and beverage alcohol under pre-war and war conditions is shown in the following tables: (See appendix)

Table 1 - Industrial alcohol production and use.
Table 2 - Production of distilled spirits (beverage alcohol).
Table 3 - Uses of specially denatured alcohol.

During the war period, due to the inadequate supply and extraordinary increase in requirements, it became necessary to control distribution and

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a/ In two periods, (August 1944 and January 1945) beverage production operations were temporarily allowed. Such operations included practically all of the distilled spirits industry and a portion of the industrial alcohol industry. According to preliminary reports, alcohol for beverage use was produced amounting to 39.2 million wine gallons (as alcohol) and 21.8 (as whiskey), totaling 61.0 million gallons diverted. These amounts are partly included in the industrial alcohol production estimated above for fiscal year 1945.

b/ Exclusive of denatured alcohol.

use of alcohol, as well as production. Recent allocations by the War Production Board for the various uses of ethyl alcohol have been as follows:

Uses	Allocations Calendar Year 1943	1944 a/	1945 a/
	Wine gallons (000 omitted)		
Direct military	39,900	27,200	34,500
Lend-lease	63,000	56,900	60,000
Synthetic rubber	126,000	329,600	342,500
Indirect military and civilian	147,900	160,300	165,000
Anti-freeze	50,800	31,800	36,000
Total	427,600	605,800	638,000

Pre-war uses of industrial alcohol are principally represented in the last two items of the above tabulation, most of the remainder constituting war requirements. Increases in civilian use above the pre-war normal are also due principally to war demands. However, the situation represents enlarged usual markets rather than significant new uses or market outlets for alcohol, except in the case of synthetic rubber. This field of use represents a new and highly significant market outlet that may reach 350 million gallons annually, at peak, and may have great post-war significance. This amount represents over 300 percent of the total pre-war annual production of industrial alcohol.

The item of "indirect military and civilian" uses in the above tabulation represents essential manufacturing for which alcohol supply has been allowed under controlled allocation. Distribution to the various lines was originally estimated about as follows: b/

Industrial uses	(1944)	
Chemical solvents	42,000	Wine gallons 190° P.
Gasoline anti-knock	25,200	(000 omitted)
Rayon and plastics	20,400	
Solvents and thinners for liquid coatings	15,000	
Cellulose, resins, etc.	12,000	
Industrial processing	9,000	
Miscellaneous	4,400	
Subtotal	128,000	

(Table continued - next page)

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a/ Revision April 25, 1945.

b/ Original estimates of 1943 amounted to 152,400,000 gallons. Requirements later were estimated at 160,700,000 gallons. (August 1944)

Table continued

Consumer uses	(1944)
Vinegar	10,000
Proprietaries	6,000
Food and medicinals (internal)	3,000
Fluid (experimental and fuel)	900
Government (excluding military)	2,400
Hospitals and science (excluding Government)	1,200
Miscellaneous	900
Subtotal	24,400
Total	152,400,000

Of these uses, the "gasoline anti-knock" item deserves further consideration, as to post-war potentialities. The anti-knock compound now used is tetraethyl lead, and the alcohol allocated for gasoline anti-knock use is principally for manufacture of this compound. However, alcohol itself can be used as a straight fuel for internal combustion engines, or as an ingredient of fuel to secure increased anti-knock or other desirable effects. This will be discussed later, since another new and significant market outlet for alcohol is thus represented. This use has been suggested in past years, but so far has failed to achieve success in this country. At present, allocation of alcohol to such use would be impossible because of the inadequate supply.

In normal times, the annual use of alcohol for anti-freeze amounts to about 29 million gallons or less, with methanol and high-boiling materials (glycerine and ethylene glycol) also being used extensively. During wartime, the lack of these other materials made necessary the allocation of 50 million gallons of alcohol for such use in 1943.

The largest single pre-war use of alcohol was for the production of acetaldehyde, acetic acid, and ethyl acetate. Acetic acid and its derivatives can be made synthetically from acetylene, and have been thus made at Niagara Falls, New York, and in Canada, for some years. A new plant has been authorized, in Texas, to make these chemicals for petroleum gases, according to report. However, the synthetic production of such acetic derivatives had not equalled the market requirements, previous to the war, due to certain limiting conditions.

Organization of the Distillation Industries

The alcohol producing industry in the United States, as constituted in the past, included three separate classes of manufacturing plants, two of which produced alcohol in concentrated form by distillation, as stated above. Thus, industrial alcohol plants may be considered as the first class; beverage distilleries producing distilled spirits (whiskey, rum, brandy, and gin) as a second class; and wineries and breweries represented a third type of (dual) industry in which alcohol was produced but usually not separated (i.e., the alcoholic product is sold in its dilute form directly as produced and no distillation process is used). Establishments known as rectifying plants also exist, which rehandle alcohol in various ways. These, however, do not *produce* alcohol. Rectifying plants, wineries, and breweries usually do not *recover* alcohol in distilled form, and practically can be excluded from consideration in this discussion. The distilled spirits industry, however, is almost equal in importance to the industrial alcohol industry as a source of alcohol.

In the above broad classification there is, however, a considerable amount of complication. Beverage distilleries in certain instances (when suitable bonding arrangements are made) in the past also have operated as industrial alcohol plants (or *vice versa*) for limited periods, losing one legal identity and assuming another temporarily. In other cases, individual industrial alcohol plants and beverage distilleries may be parts of one common parent organization, sometimes occupying adjoining premises. Some industrial alcohol plants may be subdivided as to raw material or equipment use, and occasionally such plant also may produce acetone and butanol under part-time or part-plant operation. Also, for example, wineries may recover alcohol from byproducts of wine production, and such alcohol may be used either as alcohol additions to fortify wines, or sold as brandy; consequently, some fruit distilleries are identical with, or attached to wineries. Fruit distilleries might also operate as grain distilleries, or vice versa. Furthermore, in the production of dealcoholized malt liquor, certain amounts of alcohol may be recovered. Rum may be denatured for industrial (nonbeverage) use. Rectifying plants may rehandle alcohol or spirits produced in other industries to produce new beverage compounds (cordials, et cetera), or to purify distilled spirits produced elsewhere. It can be seen, therefore, that the industry is quite complex, when considered as a whole.

The above discussion considers only alcohol produced by *fermentation* methods. However, alcohol (high-proof) is also produced *synthetically* from petroleum, and also is recovered as a byproduct of certain industrial chemical operations. These products are classed as industrial alcohol and represent a very significant part of the total production of such alcohol.

As a result of the general pre-war situation, and of the separate legal status which had been effected, the industrial alcohol and distilled spirits (beverage) industries had become quite distinct from each other in many ways. Industrial alcohol production has been a highly competitive business, usually operating on a narrow margin of profit, whereas beverage alcohol production usually has constituted a *specialty* business, with greater possibility for profit. This fact alone has resulted in differences between the two industries as to plant equipment and methods, relative amount of labor used, and other plant practices. With the exception of those industrial alcohol plants which were actually grain distilleries, and which usually operated only occasionally as industrial plants to make high-proof alcohol for liquor blending purposes, usually for their own use, practically all the fermentation-type of industrial alcohol plants were designed to use molasses, and possessed practically no grain-handling equipment. Conversely, no molasses was used in plants making beverage alcohol, except in the case of rum manufacture. Also, practically no molasses-using industrial alcohol plants were equipped to recover grain residues or byproducts.

The pre-war annual alcohol production capacity of the country was somewhat equally divided between the industrial alcohol and distilled spirits industries, each industry having an estimated nominal gross potential output capacity of perhaps 250 million wine gallons. However, such capacity had never been reached actually or even exactly determined.[a] For many years previous to the war, the industrial alcohol industry had operated at reduced production rates, representing 40 to 70 percent of normal, due to market limitations. The distilled spirits industry, after operating at comparatively full rate for several years following Prohibition repeal in 1933, had also fallen off to a lowered annual production after the warehouses were filled with a 5-year supply of liquor. The impact of the war changed the situation. Molasses imports were cut off, throwing seaboard industrial alcohol plants out of production, while export needs and requirements for munitions disturbed the industrial alcohol markets by exhausting stocks. In the emergency, attempts were made to revamp molasses-using plants for use of grain (particularly as granular wheat flour), but critical conditions with regard to machinery often prevented proper installations, while congested railroad traffic affected movement of grain. As a further emergency step, beverage alcohol manufacture was stopped in distilled spirits plants and these plants were converted wholly and exclusively to the production of industrial alcohol. Most of the smaller distilleries lacked refining equipment adequate for producing (high-proof) industrial alcohol, but instead produced "wines" of about 70 percent concentration, which had to be shipped elsewhere for refining.

These changes represented a virtual merging of the two distinct industries on an emergency basis, and much trading of equipment and uneconomic cross-hauling of raw materials and "wines" resulted, together with significant losses of potential byproduct feed materials. As an agricultural complication to all this, grain and feed shortages developed due to increased stock raising and war demands, which made it necessary to allocate grain-handling and byproduct recovery equipment to alcohol plants and distilleries which previously had none. The handling of the complex situation in the earlier period necessarily was influenced by emergency requirements rather than by actual intent to improve the ultimate welfare of the two industries. Effort later was made, where possible, to have alcohol plants return to the types of raw material and alcohol production for which they were best suited,

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[a] In the peak pre-war year (1937) distilleries produced 258.96 million proof gallons and industrial alcohol plants produced 223.18 million. The combined total therefore, was only about 250 million wine gallons, 190° proof. (See tables 1 and 2, appendix.)

since the resumption of molasses importation in 1944 permitted the more or less complete return of seaboard industrial alcohol plants to their normal raw material, whereby increased alcohol production was achieved. Impending sugar shortages in 1945 have again reversed this situation, however.

Also within the emergency period, a shortage of corn, the grain usually employed in greatest amount, brought about the substitution of wheat, with which the average distiller had no experience. An impelling reason for this shift was a then-existing surplus of wheat. Use of wheat introduced processing difficulties, which eventually were overcome by research cooperation of Government and industry. Other materials also were employed because of fluctuations of supplies of both wheat and corn, or because of current surpluses of such other materials. Recent large crops could permit a more general return to corn in 1945, but thus far restrictions have existed.

It should be remembered that the beverage alcohol industry experienced a period of virtual extinction during the Prohibition era. Owing to this fact and to the great competition in both the industrial alcohol and distilled spirits markets, there had been little incentive heretofore to modernize either industry or to build new plants. Some few new and modern plants of high production efficiencies were completed in post-Prohibition years, but otherwise these industries largely remained in status quo. Most of the plants built were beverage distilleries, which rushed into production after repeal of the Prohibition Act. Recently, due to increasing alcohol requirements during the war, some large industrial alcohol plants have been built; some of which are of more or less adequate design or construction because of limited construction facilities and time. Some of these are converted breweries. Also a few older, smaller plants, formerly uneconomic, have recommenced operation. Almost all of the new fermentation plants are designed to operate on grain and are located in the midwestern grain-producing areas. However, there have been considerable additions to the producing capacities of older grain-, molasses-, and synthetic-alcohol plants. New synthetic plants also have been built, as well as plants to operate on wood or on sulfite liquor.

The geographic location of existing plants is related to the kind of raw material originally used. Since all older plants were designed to use one class of raw material <u>only</u>, the tendency was to locate them in proximity to such raw material. Thus molasses-using plants are located on waterways (principally at eastern, western, and Gulf seaboard ports); grain-using plants are in or near the grain-producing areas of Indiana, Illinois, Kentucky, Maryland, and Pennsylvania; while synthetic-alcohol plants are located near gas or oil supplies. Wood and sulfite liquor plants are located in the Pacific Northwest, near forest areas. Any future attempts to use dual raw materials of different type in the same plant will probably introduce haulage and waste disposal problems. From a technical standpoint, the use of molasses in grain-using plants is relatively easy, involving little change or new equipment, but, conversely, the use of grain in molasses-using plants necessitates extensive change and addition.

As now constituted, the industrial alcohol industry is an assemblage of various groups of plants, each group being composed of plants having some similarity as to raw material used, type of product, or geographical location. These production groups are relatively non-related. Actual output for the industry is dependent upon the functioning activity within each group. It is not possible to anticipate over-all yields from the whole industry by a mere summation of the total output capacities of the various groups under operating conditions favoring production (wholly ethyl-alcohol operation), since other factors may intervene. However, a summation to secure an estimate of actual potential output would be possible if the conditions that govern each group were known. The present organization of the industry is shown in table 4 (see appendix). However, changes are occurring continuously. Erection of several additional grain plants has been contemplated. These plants, based on grain operation, would be located in the Corn Belt States near the Mississippi. Expansions in older plants are also taking place.

The group of plants which produce butanol and acetone merit special discussion. Usually, in this group, grain and molasses can be used alternatively as raw materials, depending upon relative price or accessibility. In the butanol process, a certain amount of ethyl alcohol ordinarily is produced as a byproduct, as indicated in the following tabulation of the butanol fermentation products from corn and molasses, (usual expectancy):

	Corn	Molasses
	(Percent by volume of total solvents produced)	
Butanol	56 - 60	68 - 72
Acetone	30 - 30	29 - 25
Ethyl alcohol	14 - 10	3 - 3
Pounds of mixed solvents	13.5 - 14.5 per bu.	1.8 - 2.0 per gal.

The alcohol thus produced usually is considered as a byproduct. However, in some instances the plant may operate simultaneously (or alternatively) as an ethyl alcohol plant, since practically all the equipment used is suitable for either process. As a consequence, it can be predicted that when comparative prices favor butanol, these plants can be depended upon for only the minimum (byproduct) ethyl alcohol production, while conversely, with poor markets or low prices for butanol (or acetone), they might operate to total capacity to produce ethyl alcohol. No definite statement can be made as to how much alcohol will be derivable from this source, unless the butanol-acetone supply and requirement situation is known. One unit of butanol production offsets or nullifies about three units of possible alcohol production. In pre-war years, the operation of these plants, as a group, probably could be estimated as about 50 percent for alcohol and 50 percent for butanol production. About 60 million gallons of molasses may be required in 1944 for butyl alcohol production, if available. Fifty-seven million gallons were used in the fiscal year 1944, and 6.95 million bushels of grain.

To complete the picture, the organization of the distilled spirits industry is shown in table 5 (see appendix). Since all these plants (except rum distilleries) use grain as raw material and produce equivalent grades of distilled spirits, significant differentiation would have to be based on size or on the relative modernity or obsolesence of the plant--or of the plant equipment. However, the plants which normally undertake duplicate operation as industrial alcohol plants (i.e., carry IAP numbers) are separately shown, since the capacity thus indicated is largely duplicated in the industrial alcohol plant capacity (table 4). (Most of the distilling industry now producing industrial alcohol in the emergency is doing so without recourse to the usual former legal method of being actually designated as an industrial alcohol plant, as now permitted by the emergency regulations recently established for the purpose.)

In post-war operation, it is possible to predict future disposition of products from some of the several industrial alcohol producing groups on the basis of past procedures, based on the necessity of saving freight or other expense. Thus, territorial plants are likely to sell their products in the territories where produced insofar as markets exist. Pure alcohol produced in beverage alcohol plants (which ordinarily do not produce denatured alcohol) is likely to be utilized more or less directly by those plants for alcoholic beverage manufacture (blending) as far as possible. Chemical plants may reuse the alcohol product within their own corporate activities. Production from all such plants, while swelling the statistical total, has little effect on the actual quantity of alcohol available for the general market, except as it lightens the over-all production load on the real industrial alcohol producers by relieving them of that much additional production which otherwise would have to be provided for.

It is somewhat doubtful if the Midwest plants can operate under post-war grain prices, or even on molasses, since they are hardly in a strategic position to secure molasses in economic competition with seaboard plants.

Alcohol Production Capacities

The alcohol production capacity of an alcohol plant is not a fixed matter; considerable fluctuation is possible. Nominal capacities were established in the past for governmental bonding purposes. Capacity in beverage plants has been computed in the past by the Alcohol Tax Unit on the basis of an estimated normal fermentation capacity of the plant, at an assumed mash concentration and fermentation period (usually 72 hours) for a definite raw material, (usually corn or rye). Obviously, increase in mash concentration or shortening of the required fermentation period by 24 hours or more might permit 33 to 50 percent increase in potential output. For some purposes (more applicable to the industrial alcohol industry), plant capacity was computed on an assumed rate of passage of alcohol vapor through the distillation columns. Such an estimate again is based on arbitrary factors, and if vapor velocities are increased, reflux ratios changed, or steam input values increased, considerable variation can be obtained, amounting to perhaps 20 percent above the assumed normal output, as a maximum.

In almost any alcohol plant, certain steps might be out of balance due to errors of design, plant additions or changes, unexpected superiority or deficiency of performance of certain items of equipment, et cetera, so that at some process point a "bottleneck" exists. Such a "bottleneck" is really the limiting factor on the capacity of that plant. It may be a matter of undersize in specific equipment, inadequate steam or water supply, inadequate distillation columns for the fermenter capacity or vice versa, inadequate byproduct feed recovery, et cetera. Frequently, by adjustment of conditions, the plant capacity can be considerably increased at relatively minor expense, although in some cases major changes would be required. In old, outmoded plants, justification for changes may not exist. However, it is obvious that an existing "bottleneck" would invalidate computed or theoretical production capacity based on the fermentation or other unit, if occurring elsewhere in the plant.

In pre-war years, regulations governing the distilled spirits industry have prohibited operations on Sunday. In order to meet this requirement, it was necessary to slow down or adjust fermentations so as not to have any material ready for distillation from Saturday night to Monday morning. This had the effect of reducing potential production of distilled spirits by at least 28.5 percent. While the industrial alcohol industry was not hampered by this restriction, labor or market conditions frequently brought about a similar slackening of operations over week ends so as to release all but a minimum staff. During the war emergency, these restrictions largely have been abandoned. In post-war operation, the restriction of week end operation may recur for beverage plants, as it was really made for the convenience of the Government, to simplify control and inspection problems.

It should be noted that plant capacities are based originally on the use of a particular raw material. Change of raw material may reduce or raise production capacities, depending on the conditions. This is particularly true in the case of grain alcohol plants, and would also apply in substitution of grain for molasses in molasses-alcohol plants.

The capacities indicated in tables 4 and 5 are based on certain arbitrary assumptions, and are subject to 10-15 percent variation, in most instances. The estimates are largely based on the theoretical or optimum performance, and may be difficult to realize on extended periods of operation. However, production in the molasses-using plants may be higher than indicated in the table, at the expense of grain use, if the molasses is economically available. Also, the price that must be paid for the molasses will have a bearing on the situation. Recently, for example, corn had a financial advantage over molasses, although this normally would not be the case.

Study of preliminary reports of actual operations of all plants producing alcohol from grain for the government program during the calendar year 1944, discloses that 136 plants, of both the industrial alcohol and distilled spirits industries, utilized 153,457,534 bushels of grain and produced 377,484,650 gallons of alcohol therefrom.1/ 2/ The grain used varied during the year, and mash bills for individual plants were not uniform during the year. The grain was whole wheat, rye, sorghum, and a little corn, with a considerable amount of granular wheat flour and some rye flour. Malt used is included.3/ This year operation probably approaches the present maximum national production capacity from grain, as many of the larger plants operated practically every day in the year, the over-all average (all plants) being about 335 days. If corn had been used in greater amounts, the production might have been increased slightly, since better yields are usually securable from corn than from rye and wheat. This factor, however, was largely offset by the percentage of granular wheat flour used, since this gives unit yields higher than corn. Production total was also affected by the fact that a few large plants had operating difficulties, or began manufacture during the year, so that a theoretical full production from these 136 plants would represent about a 14 percent increase over the actual performance. Based on a 350-day year, at assumed performance rates equal to the best single month's operation (during 1944) for each individual plant, the theoretical capacity of these plants would total about 445,000,000 wine gallons of alcohol, utilizing approximately 185 million bushels of grain. However, it might be difficult to attain this performance, in actuality.

The above plants comprised:

(a) 10 - Industrial alcohol plants
(b) 16 - Industrial alcohol plants (duplicated as beverage distilleries)
(c) 92 - Beverage distilleries (exclusive of (b), producing high proof alcohol)
(d) 18 - Beverage distilleries (exclusive of (b), producing only low proof alcohol for redistillation)

In addition to such production from grain, 24 industrial alcohol plants utilized molasses (356,099,692 gallons) to produce 152,528,971 gallons of alcohol, in the same year, on the government program. Two plants under (a) above operated on both molasses and grain. Total production in these 158 fermentation plants was 530,013,621 wine gallons, (basis 190° proof) 1/ 2/.

Since only a few (smaller) plants were inactive, practically all plants being incorporated in the government program, this summation represents about the maximum present production expectancy for the fermentation industry. Raw material and product prices will stimulate or retard maximum activity. Total industrial alcohol production for the calendar year 1944 amounted to 585.2 million gallons according to Alcohol Tax Unit reports. An additional 7.5 million gallons were produced as whiskey.

1/ Preliminary figures. About 18 small plants were inactive or failed to report.

2/ Inclusive of beverage holiday production in August 1944, for industrial alcohol.

3/ Ten to twelve percent of the total grain at various plants, averaging 10 percent over-all.

As a summarization, the statistical values heretofore discussed are restated in table 6 (see page 14) to show, in rounded figures, the present and future alcohol situation. It must be understood that, in this analysis, detailed and accurate information was not entirely available, and this presentation is subject to later amendment if and when additional or more accurate data are secured.

Foreign Alcohol Situation

Until recently the United States has been an export Nation in respect to alcohol, rather than an import Nation. Due to war demands the situation has reversed and importation has been increasing.[a] The increased United States demand has stimulated the fermentation alcohol and beverage industries in foreign countries, particularly in the Caribbean area, and in some countries relatively great expansions are taking place. Seventy-six distilling operations are understood to be operating or nearing completion in Cuba. An eventual development of capacity to produce 150 million gallons of alcohol annually is forecast for the Mexican and Caribbean area. With Canadian production, a potential importation of perhaps 60-100 million gallons eventually might be conceivable, although actually local uses will reduce the potential amount. Much alcohol is used for motor fuel in the Caribbean area.

Such foreign alcohol production may have a noticeable but perhaps not too serious effect on the United States industry. Thus, future exportation of alcohol from this country may be limited because certain countries have developed their own supplies, because of cheaper foreign production, or because of shipping costs. The availability of foreign alcohol stocks in large quantities might constitute a limitation on the price obtainable for alcohol within the United States, subject to tariff or protocol limitations. In effect, a ceiling is created. A few United States alcohol producers are understood to be contemplating extending their production in foreign establishments, particularly to tropical areas. Since fermentation alcohol is produced from carbohydrates, and since carbohydrates are produced cheaply in the tropics, while labor is also cheap in such areas, such extensions may be financially attractive if other costs do not nullify the obvious advantages.

Full information is not available on the actual production of alcohol abroad, but table 7 presents such figures as are available. Inasmuch as many countries do not keep adequate statistics of alcohol production, and since there is much confusion as to whether industrial or beverage alcohol, or both, are included in published figures, while the alcohol concentration, units of measurement, et cetera, are frequently not clarified, too much dependence should not be placed on these figures. Obviously, the European situation depicted in the table is now obsolete, while in other instances the production has undoubtedly been considerably expanded. Where differing figures are shown for a country, different information sources are indicated.

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[a] In 1943 about 12 million gallons of industrial alcohol were imported from Canada and Mexico. Importation from Cuba began in 1944. Importation in 1942 was negligible, but reached 33 million gallons in 1944.

Table 6.- Summary of production capacity distribution

Industrial alcohol plants	No. of plants	Present		Future 3/	
		Actual rate 1944 1/	Theo. max. 1944 2/	Probable	Maximum
		Millions of gallons - 190 P.			
(A)					
1. Synthetic alcohol	4	59	76.65	55	90
2. Chemical byproduct	3	1	2.80	2	4
Subtotal (A)	7	60	79.45	57	94
(B)					
1. Molasses - regular	18	153	198.73	150	220
2. Wineries (alcohol from molasses)	8		9.94	3	10
3. Territorial (molasses)	3		10.50	5	10
Subtotal (B)	29	153	219.17	158	240
(C)					
1. Grain - regular	12	113	140.17	90	140
2. Miscellaneous (including sulfite)	5	3	3.22	5	10
Total - Actual Industry	53	329	442.01	310	484
Grain Distilleries					
(D)					
1. Operating also as industrial alcohol plants	17	99	106.01	100	110
2. Regular, producing high proof alcohol	92	178	186.70	170	190
3. Regular, producing low proof alcohol	20	11	14.35	10	12
4. Miscellaneous (rum, etc.)	7	2	3.88	2	4
Total (D)	136	290 4/	310.94	282	316
(E)					
1. Butyl plants (byproduct alcohol)	4	(?) 4	(80.4-110)	(?) 4	(?)
Grand total	193	623	753	596	800

1/ Based on 1944 production, including beverage production August 1944, plus inactive plants.

2/ Probable normal operation basis, theoretical maximum (350-day operation) values, on the assumption that war ended suddenly and all plants reverted to pre-war or normal status (i.e., the distillers to beverage production, butyl plants wholly to butyl production, etc.). Inactive plants included where known.

3/ Range shown from probable to maximum operation. In case of shortages of industrial alcohol at attractive price scales, groups of plants such as distilleries (D-1) or butyl (E-1) might shift to such production, all or in part. Conversely, with advantageous beverage alcohol prices, groups such as B-1, B-2, or C-1 might shift in part to beverage production.

4/ Beverage distillery capacity (124 plants) recently was estimated at 265 million gallons by W. G. Whitman, War Production Board.

Alcohol from Agricultural Products

In the case of the fermentation alcohol industry, fortunately so much flexibility exists as to raw materials and methods of operation that adaptation can be made to meet any reasonable program. While the actual fermentation step itself is, of course, limited to such conditions as are suitable for yeast functioning, practically all other plant operation conditions can be varied in many ways while still producing suitable commercial end products. Naturally, when the highest operating efficiencies and lowest product costs are considered, the nature of plant design becomes more restricted, but it is possible to make many compromises of design, or to employ many suitable alternate procedures so as to successfully utilize plants of older or semi-obsolete design. As shown above, the combined alcohol distilling industries consist of about 189 commercial plants, most of which primarily are beverage alcohol distilleries. No plants are exactly alike in design, size, type of equipment, raw material use, or even in operating procedure, and yet a great majority of them are commercially competitive. All new developments in alcohol production methods can be applied more or less easily to almost any existing plant.

The alcohol produced by fermentation from any starch- or sugar-bearing agricultural crop is inherently suitable for any industrial purpose for which alcohol is employed, regardless of the original raw material used, process conditions, or other factors. Practically no limitations of such use exist, and source material or use may be interchangeable (assuming adequate purification). End products are obtained in practically all plants, which are comformable to fixed specification and which are relatively uniform and interchangeable. Consequently, all such products may be pooled for use and it is unnecessary to consider technique in the alcohol-use industries, such as synthetic rubber for example; therefore, these questions may be eliminated from this discussion, except perhaps as to the relative economy of using alcohol instead of some other alternative raw material. It may even be possible to deviate from present standards of alcohol quality, in instances, to improve the economic or competitive position of alcohol as such raw material. The only restrictions on the use of industrial alcohol produced from farm crops, particularly cereals, that might be of significance are in the actual supply of these raw materials and the factor of relative cost, since the same alcohol can often be produced more cheaply from other raw materials which also are available at present in large quantities. (In the case of beverage alcohol the field narrows down to a few specific agricultural raw materials (cereals), and cost becomes a less major consideration due to higher possible sales returns.)

As far as the use of specific agricultural commodities as alcohol raw materials is concerned, again great flexibility exists. Any carbohydrate crop containing sugar or starch, which can be converted easily to fermentable sugar, can serve as alcohol raw material. It is merely a matter of cost. With suitable and usually not too extensive plant additions, any existing plant could be adjusted to handle any potential raw material.

For most industrial uses, alcohol obtained synthetically from petroleum or other sources, or produced by fermentation of sugars derived from the cellulose of wood, can likewise be used. However, for certain industrial uses (as cosmetic solvents, for example), and for uses involving the subsequent internal consumption of the alcohol by human beings (as pharmaceuticals, flavorings, etc.), alcohol from these latter sources may not always be acceptable to the trade, due to predjudice based on the source, or to the possible presence of impurities. In the case of alcohol for synthetic rubber, munitions, or motor fuel, distinctions as to origin are not significant technically.

Concerning raw materials, it may be anticipated that the post-war market situation for industrial alcohol will tend to revert to pre-war prices and conditions, in which case waste molasses will probably emerge as the cheapest source of industrial alcohol (other than synthetic alcohol). Some developments from the production of alcohol from sulfite pulp mill liquor, agricultural residues, or wood itself, possibly within the same general cost bracket, may be expected. On the other hand, the production of alcohol from grain will entail higher production costs, as explained hereinafter, and will be economic only with full byproduct feed recovery at adequate prices. Relatively ample stocks of molasses will doubtless be available continually, as needed, to meet the demands for usual industrial alcohol needs, exclusive of motor fuel use. Grain stocks will likewise be ample, but consideration by the alcohol industry will doubtless be given mostly to the more economic types of grain, such as corn, grain sorghum, rye, and wheat, which were used heretofore.

In the United States the bulk of the raw material used for the pre-war production of industrial alcohol by fermentation has been molasses. Such molasses was largely imported, and formerly consisted principally of so-called blackstrap, produced as a byproduct or residue from cane sugar operations, which contained about 55 percent of sugars, both sucrose and invert. Subsequent to about 1933 when the sugar quota was in effect, so-called "high test" molasses was also largely used. This molasses represented hydrolyzed cane juice or raw sugar, and contained about 75 percent total sugars, mostly invert. It was produced by foreign sugarcane growers in an effort to keep their organizations functioning under restricted market conditions, since it could be shipped into the United States, regardless of the sugar quota, if for industrial use.[a] Blackstrap was obtainable at seaboard alcohol plants as low as 3 to 5 cents a gallon, and high test molasses sold at equivalent prices based on sugar content; therefore, no other raw material could compete for industrial alcohol production except, of course, byproducts of petroleum cracking which were used for synthetic alcohol. In recent pre-war years the molasses gallonage consumed for alcohol manufacture has varied from 160 to 225 million gallons (including both high test molasses and ordinary blackstrap). The maximum pre-war amount used was 268 million gallons (1926).

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a/ Use of high test molasses has continued, but it probably will not be available in 1945, due to the short crop.

Cuba produces about 54 percent of the cane sugar from the Caribbean area, Puerto Rico producing 16 percent, the Dominican Replublic about 7 percent, and the Gulf States about 6 percent. Blackstrap molasses production is approximately proportional to sugar output (about 50 gallons per long ton of sugar). Sugar production has fluctuated in past years in various areas, and Cuban blackstrap production has ranged from 110 to 230 million gallons, 150 million gallons being perhaps a normal figure. Cuba also has produced as much as 331 million gallons of invert (1941). The only other country producing invert is the Dominican Republic (around 20 million gallons). Cuba normally supplies about 75 percent of the total United States imports of industrial molasses. After 1946 supplies should again be available from Java, Philippine Islands, and Hawaii. Much expansion of sugar production is possible, in all areas. Ordinarily, perhaps 225 million gallons blackstrap and 200 million gallons of invert might be obtainable by the United States annually, under pre-war status. About 75 percent of the molasses imported was used for alcohol production, 20 percent going into stock feeds, and about 5 percent into butyl alcohol, citric acid, yeast, and vinegar production. However, there has been considerable development in alcohol and yeast production in Caribbean countries, particularly Cuba, which may tend to reduce the quantities of alcohol formerly available. In 1944, Cuba used about 120 million gallons of her total blackstrap production of 230 million gallons. Future molasses prices may therefore be higher than pre-war, affecting the relative commodity use if the price goes too high.

It may be assumed, however, that all molasses-type plants will continue to use this raw material principally, and in most cases, exclusively. Thus, the 29 potential molasses-using plants might account for an annual production of 133-220 million gallons of alcohol per year (exclusive of alcohol from molasses-using butyl alcohol plants). Since about 2½ gallons of blackstrap, or 1.75 gallons of invert or high test molasses are required for each wine gallon of 95 percent alcohol produced, the molasses requirement can easily be computed once the actual relative amount of each type of molasses available is known (322 million gallons, if all blackstrap, or 226 million, if all high test, for producing 133 million gallon of alcohol). It is believed that sufficient molasses will be available for perhaps 15.0 million gallons alcohol production, if required by the situation.

In pre-war operations, a small amount of grain, principally corn, was used in industrial alcohol production, but the particular alcohol produced therefrom was intended principally for ultimate use in beverages; and, while normally classed as industrial alcohol, was actually beverage alcohol and usually was produced at beverage alcohol distilleries for trade use when operating temporarily as industrial alcohol plants. Use of cereal grains (exclusive of granular flours) for alcohol production had been almost wholly by beverage alcohol manufacturers up to 1943, since only they had the necessary processing equipment. (Tables 4 and 5, see appendix.) Some molasses-type industrial alcohol plants recently have been equipped to use whole grain.

The use of grain[a] will be confined largely to the beverage alcohol industry, since these plants are situated and equipped for grain processing while most molasses-using plants are not, and since trade requirements tend to discourage the use of molasses in the beverage alcohol industry, exclusive of rum manufacture.[b] The new grain using industrial alcohol plants of the midwest are likely to be in a disadvantageous position, if grain costs are above economic levels. The grains which will probably enter the field are corn, rye, barley, grain sorghums, and wheat, as in the past. Possible yields from these grains ma be listed as follows:

	Anticipated gallons (95% alcohol per 56-pound bushel)	Pounds of feed by-product per bushel at full recovery
Corn	2.5	18.0
Rye	2.2	19.0
Barley (as malt)	2.2	21.0
Soft wheat	2.4	20.0
Grain sorghum	2.2	18.0

Any use of other farm crops, such as potatoes,[c] fruit, sugarcane tops, sorghums, and citrus wastes, as well as uncultivated plants, such as sotol, and wastes from starch factories and sulfite pulp plants as secondary fermentation materials, probably will be confined to industrial alcohol manufacture,

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[a] Grain allocation for alcohol in 1944 originally was 170 million bushels, equivalent to 425 million gallons of 190-proof alcohol. Wheat use was 107 million bushels in 1943-4 crop year (Wheat Situation July 1944). Some rye, barley, and sorghum were also used. Corn, however, was withdrawn from use during the year. During 1943-4, a shortage of wheat developed. Indicated requirements in bushels to July 1, 1944, for wheat, included human food, 545 million; animal feed, 517; alcohol, 107; exports, less than 50; and seed, 79 million. An estimated 1,452 million bushels of U. S.-grown wheat were available, leaving 150-160 million as margin, the lowest in a long period. Three hundred million bushels is considered to be a minimum safe figure. Deficiencies had to be made up from Canadian wheat. Total grain use for alcohol in 1944 was estimated at 150-170 million bushels, much of which was to be wheat. Actual use in 1944 was whole wheat 71.0 million, granular wheat flour 36.0 million, corn 5.0 million, sorghum 16.0 million, rye 9.0 million, and malt 15.0 million bushels.

[b] If pure alcohol is used to blend or "stretch" straight whiskies, it must be declared on the label of the final package, and such alcohol was always designated by the competitive trade as "neutral spirits distilled from grain." Recently, during the liquor shortage, there has been some deviation from former standards, but this change will likely be of temporary nature. Obviously, use of alcohol from other than grain sources, when stated on the label, will adversely affect product sales values.

[c] Three small plants are now producing beverage alcohol from potatoes.

since these materials ordinarily do not yield suitable distillates for beverage use, or else involve high comparative alcohol costs. In the event alcohol is used in large quantities as a motor fuel adjunct, especially on the basis of a scavenger industry utilizing excess or wasting raw materials, these commodities, as well as grains, may be used in spite of disadvantageous costs, since motor fuel alcohol production in large amounts may require all available material. Such production doubtless would have to be subsidized in order to permit the competitive use of alcohol with gasoline, and such a subsidy could and should be adjusted to take up the cost differences in producing alcohol from the several commodities.[a]

Sources of Alcohol

Ethyl alcohol may be derived from three classes of agricultural raw materials: Saccharine materials (containing sugar, such as molasses, sugar beets, sorghum cane, sugarcane, etc.); starchy materials (cereal grains, potatoes, etc.); and cellulosic materials (wood, agricultural residues, and the waste sulfite liquor from paper pulp mills which contains sugars from cellulose and hemicellulose hydrolysis).

In the first two cases, the traditional fermentation method of alcohol production is employed. Either the raw material is one of the simpler sugars, in which case it can be fermented directly to alcohol by one of a number of varieties of yeast; or it is one of the more complex carbohydrates (starch, inulin), which first must be broken down to simple sugars before the yeast can do its work. In the last instance, the cellulosic constituents of wood or other vegetation, normally unfermentable by yeast, may be converted directly to fermentable sugars by hydrolysis with mineral acids. Similar production of fermentable sugars is accomplished to some extent in the production of paper pulp from wood by the sulfite process, the sugars resulting from the chemical treatment remaining in the waste liquor as a dilute solution. After suitable purification of these sugar solutions, as derived by either method, yeast fermentation may be conducted, as in the case of grain. However, the alcohol thus produced may find limitations as to use, and some of the sugars are not fermentable to alcohol by yeast, so that total utilization is not effected.

Saccharine Materials

The principal saccharine raw materials are sugarcane, sugar beets, and the byproduct molasses from sugar processing. However, fruit, sorghum cane, nipa palm and similar materials also fall in this classification. All these materials have an advantage over starchy materials, such as potatoes and corn, in that most of their soluble carbohydrate is already in suitable form (sugar) for transformation into alcohol by the action of yeast, whereas starch-bearing raw materials must first be treated with enzyme, such as

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a/ Motor Fuels from Farm Products, Miscellaneous Publication 327, USDA (Conclusions).

diastase, or with dilute acid, to convert the starch into sugar before fermentation can take place. The most used saccharine material is molasses. (The molasses supply situation is discussed elsewhere in this report.)

In France, the sugar beet formerly constituted one of the most important sources of alcohol, but in the United States, alcohol is not made directly from beets. This was tried commercially in Utah a number of years ago, but the plant was not successful. The juice of the sugar beet contains a variable proportion of fermentable sugar, and beets of good quality should yield approximately 23 gallons of 99.5 percent alcohol per ton. Beet molasses, obtained as a byproduct in the manufacture of beet sugar, has been used occasionally for the production of alcohol, but production from this source is negligible. Beet molasses is used more largely for the production of yeast and fermentation citric acid. This molasses also has high value as a stock feed ingredient. Such uses remove it from the market as a potential alcohol raw material.

Under certain conditions in the world sugar markets, it may perhaps be economically feasible to produce industrial alcohol by the direct fermentation of sugarcane juice. Actual plant operations in Cuba, as reported in 1933, indicated that 95 percent alcohol might be manufactured from sugarcane juice at a cost of around 7.2 cents per gallon, including charges for materials, labor, conversion, supervision, and taxes, at values then current. Computing sugar in juice at 1 cent per pound ($2.00 per ton for cane), alcohol costs of about 20 cents per gallon are indicated.[a] Alcohol has also been produced very cheaply in tropical countries from the sap of the nipa palm and similar sugar sources. Pineapple waste, which contains usable amounts of sugar, serves as a commercial source of industrial alcohol in Hawaii.

During the season of 1942, under a project sponsored by the U. S. Department of Agriculture and financed by the Commodity Credit Corporation, a total of 23,252 tons of sorghum cane were employed for alcohol production on an experimental basis. From this cane, 351,401 gallons of syrup of 78 percent solids content was produced by cane sugar factories during inactive periods, thus utilizing idle equipment. This was shipped to Harvey, Louisiana, and processed to alcohol by one of the molasses alcohol plants located there. This trial operation produced alcohol at a critical time, from a hitherto unused raw material, and saved tanker and tank car movements. It also saved the shipment of equivalent grain and obviated the need for installing grain handling machinery. Only a short 100-mile haul was involved in transporting the syrup to the distillery. Based on quantity and nature of the raw material, the experiment should have provided about 206,700 gallons of alcohol, although actual yield is not known.

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[a] These values might be bettered in Cuba under certain trade conditions.

It is not probable that such operation could be conducted in competition with byproduct sugarcane molasses in normal times. Installation of fermentation equipment at sugar factories, however, would eliminate a considerable amount of evaporation otherwise necessary to concentrate the material for shipment under the most economical conditions. Since fermentation is conducted at about 12 to 16 percent sugar concentration, in comparison with the 78 percent concentration required for shipment, a considerable simplification might result. Also, the use of evaporators as stills to produce low-grade alcohol, which subsequently could be shipped to rectifying plants, might help to offset present costs. The development of a sorgo sugar industry might provide quantities of a low-grade byproduct, sorgo molasses. The use of the sorgo seed and bagasse as feed would have important application in the South. About 5 pounds of aconitic acid and 10 pounds of starch per ton of sorgo might also be obtained as byproducts, with suitable change of the processing method.

During the season of 1942, likewise, the use of waste liquor from the pressing of citrus pomace (from citrus juice extraction plants) prior to drying the pomace for cattle feed was tested for alcohol production. About 1,800 gallons of waste press liquor, containing about 6.6 percent sugar, resulted from each ton of dry citrus feed produced. Current production of citrus feed was 47,376 tons annually (in Florida). From the 85 million gallons of press liquor thus represented, about 3.1 million gallons of alcohol is potentially available. This represents the maximum production from the waste of the present 8 drying plants now in operation in Florida.[a] Information is lacking as to the situation in Texas and California. Certain byproducts, such as hesperidin and naringen and their derivatives, might be recovered also.

Almost any fruit can serve as a direct source of alcohol. Sugar contents range about as follows: (Range (basis, fruit as received))

	Percent		Percent
Apples	10.0 - 12.0	Muskmelons	3.8 - 5.8
Apricots	10.4 - 13.0	Oranges	6.0 - 8.8
Cherries	11.6 - 15.0	Peaches	8.7 - 11.6
Figs (fresh)	16.0 - 20.0	Pears	8.9 - 10.0
Grapefruit	4.4 - 6.6	Pineapples	11.9 - 15.0
Grapes	11.5 - 15.0	Plums	8.3 - 12.5

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[a] Statement from Southern Regional Research Laboratory 1943. According to the War Food Administration, six plants in Florida produced citrus molasses (14,500 tons) in 1944, plus 67,130 tons of dry feed. Six plants in the Texas area, and 6 plants in the California-Arizona area also recovered feed, but did not produce molasses. These 12 plants had a total output of 20,471 tons of feed.

These sugar percentages are sufficiently high that the the mash concentrations would approach usual commercial practice, when the pressed juice, or the macerated fruit, were fermented directly. Chief disadvantages of fruit as raw material for alcohol lie in the relatively high cost and the perishable nature of the material. Apples are used for the production of beverage spirits (apple brandy), and pineapple juice or waste is used (in Hawaii) as a source of industrial alcohol. Dried fruits, such as dates, figs, prunes, raisins, etc., would serve more successfully, since storage of the materials would be possible for reasonable periods, and since sugar concentrations are greatly increased (figs, 45.0 to 50.0 percent; prunes, 55.0 to 60.0 percent; raisins, 62.0 to 68.0 percent; and dates, 60.0 to 70.0 percent). The relative cost of these materials is ordinarily too high to permit competition with those generally used, molasses or cereal grains, for example.

Starchy Materials

The principal starchy materials which may be used in making industrial alcohol are: (1) Cereals (corn, grain sorghum, oats, rye, wheat, barley, and rice); (2) potatoes; (3) sweetpotatoes; and (4) miscellaneous crops such as Jerusalem artichokes (Girasole), sotol, etc. Actually, only corn, grain sorghum, wheat, rye, barley, and potatoes have been used commercially in this country. Rice has been used in the Orient. Wheat, rye, barley, and other cereals usually command relatively high prices as foodstuffs, which restrict their use as raw materials for alcohol, except for beverage alcohol manufacture. Barley in the form of malt is used rather extensively as a source of enzyme for the conversion of starch to fermentable sugar, but otherwise normally finds little application in the production of industrial alcohol in the United States. In general, alcohol yields are in direct relation to starch content, under proper processing conditions, so the relative value of any grain in this respect can be determined easily. However, each grain requires different processing conditions, and the yields of unfermentable byproducts will vary for each. These factors constitute the economic limitations on the selection of any grain as alcohol raw material.

Corn, our most abundant cereal, was used to some extent in the manufacture of industrial alcohol previous to World War II, but such use was usually limited by high cost, and the alcohol produced from grain commanded a premium. The use of corn has been mostly limited to beverage alcohol production (see table 2), where it is the principal source of whiskey.

Grain sorghum is nearly comparable to corn as to yield, methods of handling and processing, etc. It has not been used so extensively as a source of alcohol in the past, but recently the use has increased.

Barley is to be considered chiefly from the standpoint of malt production, since any alcohol production from grain will require malt for the starch conversion step, unless acid saccharification or the use of mold enzymes is resorted to. Present malting capacity in the United States is about 98 million bushels of malt per year. Ordinary requirements for malted beverage (beer) production reached 71 million bushels in 1942, and an even higher rate was reached early in 1943. An additional 10 million was utilized for food, lend-lease export, etc., while consumption by the alcohol industry was 25-30 million bushels. In order to relieve the situation, use of malt by brewers was cut to 70 percent of normal, and additional plants to produce malt are contemplated. The use for 1944 was 68.5 million for beer, 25.6 million for alcohol, and 10 million for food and export. About 1.1 bushels (37.4 lbs.) of dry, desprouted malt are produced from one bushel (48 lbs.) of original barley (i.e., 75-78 percent yield). The sprouts, which contain little enzyme but considerable nitrogen, are separated in the malting process and used largely as nutrient material for fermentations.

Rye is used principally for whiskey production, where it serves as basis for a special type of product. Use for industrial alcohol is incidental. However, although more difficult to process than corn, the relative costs are usually such as to permit substitution for corn as raw material. Rye is also used to some extent for malt production. Because of current availability, the use of rye is being stressed for war alcohol.

Wheat: Because of the recent relatively large wheat surplus, and the facts that wheat ordinarily does not find industrial uses and is not so acceptable for feed as corn, stress was temporarily placed on the substitution of wheat for corn as a source of alcohol, to conserve cornstocks. The wheat protein (gluten), however, introduces certain processing difficulties, such as foaming of mashes and fouling of byproduct recovery equipment, which are not experienced in the same degree with corn. Such difficulties are not sufficient to interfere with the industrial utilization of wheat, although relative plant output capacities may be slightly diminished and processing costs somewhat increased. Mixtures of corn and wheat ordinarily are handled without trouble in usual plant equipment when the wheat percentage is below 50 percent of the mixture, and plant output capacities then are not adversely affected. Use of granular wheat flour actually permits increased unit production, since the starch content of the flour is higher than that of the original wheat. Soft wheats with lower protein and higher starch contents may prove to be more acceptable as distillery materials than hard high-protein wheats which would yield less alcohol because of their usually lower starch contents. Wheat varieties show much wider ranges of starch and protein contents than are shown by corn varieties. Selection of wheat for alcohol production must therefore be made more critically.

Potatoes were formerly very largely used for alcohol production in Germany, where they were an important agricultural crop. Special types of potatoes of high starch content were developed for the purpose, and the technological features of handling the material in small plants were extensively worked out. The pre-war manufacture and distribution of alcohol in Germany was controlled by the government. Such use of potatoes for alcohol production in pre-war years was designed to benefit agriculture through advantages derived from crop rotation, stock feeding, and other benefits of an indirect, although important economic character. In the United States, the manufacture of alcohol from potatoes had never attained any commercial importance before the war, and was not an attractive commercial venture, because molasses and corn represent more abundant, more concentrated, less perishable, and relatively cheaper sources of alcohol than potatoes. The State of Idaho has operated an experimental alcohol plant at Idaho Falls in an effort to deal with the potato cull problem. Further operation of this plant, under private management, is now being carried on. Several small plants have produced beverage spirits from potatoes in the war emergency. Use of potatoes, however, resulted largely from the fact that potatoes were available without restriction.

In 1944, as an emergency measure, the War Food Administration conducted commercial trials of processing surplus potatoes into alcohol, by dehydrating the potatoes in inactive beet sugar plants and shipping the dried flaked product to alcohol plants for the alcohol conversion step. This scheme has not been an economic success. The machinery available in the beet plants was not quite adapted for potato handling, so that plant output capacities were somewhat reduced, while serious starch losses were incurred. Also, the dried product was variable, ranging from under-dried to greatly over-dried material. Under-dried flakes tended to heat and cake in shipment, causing considerable unloading and handling difficulty at the alcohol plant. Over-dried material was difficult to process and gave lower alcohol yields due to some of the starch being reverted. Incidentally, since the handling equipment available at most alcohol plants was originally designed for grain, it was somewhat inadequate for moving the new material, so that much hand labor was entailed. However, in general, the dried flakes were approximately equivalent to corn as to alcohol yield and processing requirements, although reduced quantities of byproduct feed were recovered.

If the situation warrants, further trials of this process may be made in the future. Regardless of the possibly more successful outcome of newer trials, and of the general desirability of finding additional operations suitable for employment of beet sugar factories in inactive times, it will not be an economic operation for normal times. Dehydration costs were stated to be about $5.00 per ton of raw potatoes processed, to which freight and potato costs must be added; consequently, the dehydrated material will cost more than corn. At present, about 7 tons of raw potatoes are required to produce 1 ton of dehydrated flakes, although this might be somewhat improved, 5.5 tons being perhaps optimum.

Sweetpotatoes, in recent years, have attracted interest as a source of industrial starch. Some varieties may contain 30 percent or more of fermentable matter. The culls of this crop might receive favorable consideration as a source of industrial alcohol, since the price that could be paid for them would be about the same as that offered by starch factories. Likewise, the overflow from the starch tables might be utilized for alcohol production, although costs of recovering alcohol from dilute solutions might be sufficiently high to make such a process uneconomical. Present growing practices, which are aimed at producing table-size products, do not approach the possibilities inherent in growing for industrial use. Employment of a long growing season, especially in areas such as Florida, can increase the unit size and acreage yields greatly over present amounts.

With indicated yields of 300 to 400 bushels to the acre, sweetpotatoes might represent yields of alcohol per acre, comparable to those represented by any cereal crop in the United States. Sweetpotatoes, however, are difficult to store, and thus present a special handling problem. From a technological standpoint, processing of sweetpotatoes into alcohol would probably be done in the same manner as with other starchy crops, that is, by steaming and crushing the raw material, saccharification of the starch, and fermentation with yeast. The slop, skins, etc., may be used as cattle food. Early technical development in Florida is expected. Dehydration of sweetpotatoes will have aspects similar to those of white potatoes.

The Jerusalem artichoke (Girasol, or wild sunflower) tuber has been proposed as a possible source of industrial alcohol. Inulin, the chief carbohydrate constituent, is easily broken down into levulose, a fermentable sugar. The production of alcohol from artichokes presents much the same technological features as from sugar beets. Commercial crops have been planted in France, but no significant production has ever been achieved in the United States. As in the case of all other farm crops, the use of artichokes for alcohol production would be wholly dependent upon the financial returns to the farmer and processer. At present there do not seem to be any signs of a development from this source. Whether cultural studies might lead to improvement in yield per acre and carbohydrate content is a question which lies beyond the scope of this report.

Sotol, a desert plant of the genus Dasylirion, which grows wild in large quantities, and frequently in great concentration, in some areas of Southern Texas, may have industrial possibilities. These plants resemble pineapples in appearance, and have large heads which weigh 20 to 50 pounds. They are obtainable simply by cutting and hauling. The head (stripped of leaves) can be chipped and extracted with hot water, preferably after cooking, to prepare a mash. Alcohol yields of 15 to 30 gallons per ton are possible. The carbohydrate present is principally inulin, which is easily hydrolyzable to fermentable sugars. Economics of this source have not been worked out, but a commercial development was recently attempted, and may result in small production of industrial alcohol.[a] Other varieties of cacti might also be utilized, such as lecheguilla, belonging to the Agave genus (of the family Amaryllidaceae). Manioc, Raspas and other tropical, high-starch materials are good alcohol sources, but are not now products of the United States.

Granular flour or meal, prepared from wheat or other cereal as raw material for alcohol production, has certain advantages for use in molasses-type plants, in that: (a) this material is of relatively higher starch (or fermentable matter) content than the original grain; (b) the necessity of installing grinding machinery is eliminated; and (c) grain byproducts (bran, etc.) suitable for stock feed, mostly are separated by the milling industry and need not be recovered at the alcohol plant, thus avoiding the necessity of installing recovery equipment and of expanding boiler plants to secure the extra steam needed to process slop to recover byproduct grains.

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[a] This enterprise has closed down (1945).

Furthermore, the use of newly discovered continuous cooking methods eliminates the necessity of installing batch pressure cooking equipment. Because of these facts, molasses alcohol plants have been able to accomplish production from grain during the molasses shortage with a minimum of changes or additions. Use of this material in plants possessing full grain processing equipment is, however, of minor importance.

Cellulosic Materials

In addition to the fermentative production of alcohol from farm crops, the possibility of such production from cellulose must be taken into account. This alcohol can originate from wood, cellulosic agricultural residues, and waste liquor from the manufacture of wood pulp by the sulfite process.

The utilization of wood for the production of ethyl alcohol entails two essential steps: (1) The hydrolysis of the cellulose of the wood to simple sugars; and (2) the fermentation of these sugars to alcohol by yeast in the usual manner. There are several general processes for carrying out the hydrolysis step. The cellulose may be saccharified by hydrolysis either with acids of low concentration at comparatively high temperatures, or with highly concentrated acids at comparatively low temperatures.

Considerable experimentation has been carried on in this country in attempts to utilize sawdust and mill waste for alcohol production, and, during World War I, two plants (at Fullerton, Louisiana, and Georgetown, South Carolina) produced ethyl alcohol commercially from sawdust.[a/] In the early work, a dilute sulfuric acid process was used. Yields equivalent to 20-23 gallons of 100 percent alcohol per ton of dry coniferous wood were obtained in small-scale experimental production, the yield being considerably less with the wood of broad-leaved trees. In plant operation, yields ranging from 21 to 23 gallons of 100 percent alcohol per ton of dry southern pine wood were obtained. The combined output was about 6,000,000 gallons annually. This method has been designated as the American process. However, alcohol yields were too low for economic success.

Alcohol production from wood wastes was itensified abroad, within the years preceding World War II, because of improvement in the saccharification procedure. Two processes were developed in Germany, in which high yields of alcohol are claimed. In one of these processes (Scholler), dilute sulfuric acid of 0.2 to 1.0 percent concentration is passed through layers of sawdust or wood chips, under pressure, and at a temperature of 170-180° C. The sugar produced in the hydrolysis is easily destroyed by the acid, and must be quickly and continuously removed. A wort containing about 4 percent of sugar is obtained. The free acid is neutralized with lime, and the wort is filtered, after which it is fermented in the usual manner. Yields of about 50 gallons of 100-percent alcohol per ton of dry coniferous wood are obtained, (or, alternatively, considerable quantities of yeast suitable for livestock feeding), as well as other sugars unfermentable by yeast, and residual lignin. About 20 commercial plants were operating on this process

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[a/] U. S. Department of Agriculture Bul. 983 (1922).

in 1941. In the second (Bergius) process, concentrated (40 percent) hydrochloric acid was used as the saccharifying agent. Sugar produced by the Bergius process must be rehydrolyzed before it can be fermented. The use of concentrated acid requires special acid-resistant material for equipment and necessitates the recovery of the acid, both of which complicate the process and increase the capital charges. For this reason, the Bergius process has not been as commercially attractive as the Scholler, especially since the latter process, or modifications thereof, permits variations in degree of hydrolysis.

A recently proposed modification of the Scholler process proposes only partial conversion of the cellulose with reduced alcohol yields (18-20 gallons), so as to leave utilizable residues. This, however, has not been attempted commercially. Another recent process, which also is a modification of the Scholler process, has been developed at the Forest Products Laboratory, Madison, Wisconsin, and takes advantage of the kinetics of cellulose saccharification. This process, in 3 to 5 hours, converts bark-free wood into sugar solutions containing 5 to 6 percent reducing material which on fermentation produces alcohol at rates of 50 to 60 gallons per ton of wood. A residue of about 30 percent of the original wood remains, which may have value for plastics. Much work has been done by the Forest Products Laboratory of this Department, on improvement of the original Scholler process and on the utilization of the lignin byproduct of this process, and a commercial plant is now being built.

The relative value of conversion processes for wood as a source of alcohol will depend on the cost of the raw material and processing, and on the utilization of the lignin and other residues so as to secure additional credits. Alcohol costs of 20-25 cents per gallon have been estimated by proponents, but such production costs depend on the actual utilization of residual lignin or ligno-celluloses. These residues may be suitable for plastics in certain instances. Vast amounts of alcohol might be produced from annual wood wastes or from cellulose in general, if an economic process were perfected. Some of the other sugars (principally pentoses) which are formed in the hydrolysis, but not attacked by the yeast, may be utilized for the production of furfural, etc., or as stock feed ingredients.

Wood wastes exist in large quantities. In the ordinary lumbering operation only about one-third of the tree is recovered as finished lumber. Economic utilization of the remainder for alcohol production would depend on location or concentration of these wastes at selected points in amounts sufficient to permit economic alcohol operation, as well as on the type of process used. These wastes sometimes are concentrated at one spot, particularly as sawdust. However, a considerable amount of such waste is now used as fuel.

It can be estimated that a plant of economic size (4,000 gallons of alcohol per day), operated by the American modified Scholler process, would have to utilize from 66 to 80 tons of wood waste per day to produce 1.4 million gallons of alcohol per year.[a] [b] [c] The number of operating mills of size sufficient to permit adjunct hydrolysis operations is somewhat limited. The actual availability--i.e., the net amount of waste available, introduces limitations. If the higher yielding American modified Scholler process is used, perhaps 78 potential sites exist where sufficient wastes might be available for the conduct of at least minimum (economic) alcohol production. However, if a low alcohol yield hydrolysis method is employed the number of potential sites becomes reduced to the larger saw mills, and may be as low as 9 locations.[d]

Alcohol produced by wood conversion may perhaps find restricted use, due to trade predjudice. A certain amount of methanol may be formed originally, which should be removed. Actual costs of production must still be demonstrated, and these are tied up with the utilization of the lignin residues for which little commercial market now exists. These may be used as plant fuel, in instances, but such use does not provide much offsetting credit values.

Similarly, cellulosic agricultural residues could be used in lieu of wood by these same processes. From 1 to 1-1/2 pounds of straw, corn stover, etc., are produced for every pound of grain raised, so that huge quantities of cellulosic material are <u>potentially</u> available. However, these are normally scattered through farming areas, and the cost of collection is an important factor. In some instances these farm residues are collected as byproducts at central points, in ordinary food or textile processing operations, (as corncobs, rice hulls, sugarcane bagasse, oat hulls, flax shives, and peanut hulls). These are now frequently used as fuel, although in a few cases, such as oat hulls for furfural manufacture and bagasse for insulation board, the concentrations are sufficiently large to support existing important supplementary industrial operations. In making alcohol from this class of material, furfural might be reclaimed as a byproduct to reduce over-all costs, since a two-stage process, selectively hydrolyzing the cellulose to produce five and six carbon sugars in succession, can be used. Economic operation may involve finding markets for residual lignin. New processes of alcohol production from cellulosic crop residues are in course of development, particularly at the Northern Regional Research Laboratory, Peoria, Illinois, where a pilot plant is to be built. Contracts for the erection of this plant have been let.

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[a] According to War Production Board estimates, the cost of a plant producing alcohol from nonfood raw materials is $500,000 or less per million gallons of annual production. This is 1.6 to 2.0 times the cost of the ordinary grain fermentation plant.

[b] The cost of the plant now being constructed at Springfield, Oregon, is estimated at $2,471,000, and will have a capacity of about 230 tons of sawdust per day. (11,500 gallons alcohol per day). Faith, Ind. Eng. Chem. 37: 11 (1945)

[c] U. S. Forest Service Cir. 1774 (January 2, 1942).

[d] Private communication.

Steps have already been taken for the commercial development of alcohol production from wood waste in the United States. One commercial plant is now being constructed at Springfield, Oregon, with Federal funds allocated by the Defense Plant Corporation with approval of the War Production Board. The plant will be operated with private capital by a local group, the Willamette Valley Wood Chemical Company. It will use the American modified Scholler process. Operation should begin in the late summer of 1945 and is expected to yield over 4 million gallons of 95 percent alcohol per year.

Alcohol may be obtained indirectly from wood by fermenting the waste liquors from the sulfite pulping process for producing paper pulp. The pulping process aims at separating lignin and some hemicellulose from the usable cellulose fiber. Derivatives of these separated compounds, together with fermentable sugar from the less-resistant fractions of cellulose, appear in the waste liquor. While alcohol recovery from this source has been commercially successful abroad, particularly in Sweden, the first commercial attempt in the United States, at Mechanicsville, New York, was unsuccessful and was abandoned, because of various uneconomic conditions. An admixture of molasses is understood to have been used in this plant to improve the alcohol recovery factors.

The waste liquor from the sulfite process contains from 2 to 3.5 percent of sugar, of which about 65 percent is fermentable to alcohol. Before such a liquor can be fermented, however, the sulfur dioxide, as well as the acetic and formic acids present in the solution, must be neutralized, usually with lime. The sulfur dioxide gas used for the original pulping action can be largely removed by aeration, before neutralization, if desired. Special types of yeast may be required. Alcohol yields are about 1 percent of the volume of liquid fermented; hence relatively large distillation capacities are required.

Recently a new commercial plant operating on sulfite liquor has begun operations at Therold, Ontario, Canada, and has been claimed to be successful.[a] Yields of 12 to 18 gallons of alcohol per ton of pulp produced are claimed; a distinctive feature of the process being the reuse of the yeast. The alcohol yield may be raised to 27 gallons per ton of pulp, if all sugars are recovered. Previous difficulties of the process were the extreme dilution of the solutions, the expense of pre-purification of the liquors, and the waste of non-fermentable sugars. If the process proves successful, a large potential source of alcohol, presumably at low cost, will be opened up. There are perhaps 35 pulp mills of sufficient size (100-tons-per-day pulp output, minimum) to carry an alcohol recovery plant, and a potential 40 million gallons of alcohol is conceivable from this source alone.[a] It is claimed that future costs, based on large operations, may be as low as 12 cents per gallon[a], although 20 cents would probably be a safer figure.[b]

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a/ Chem. and Metall. Engin., December 1943, p. 107. (J. R. Callaham)

b/ This process has been commercially employed extensively in Sweden and Norway. Costs of alcohol ran about 18 cents per gallon, (basis--in tanks, at works, without profit), according to private information received.

However, due to possible contamination with methanol (wood alcohol) the use of the product might be restricted in certain fields. The methanol is removed by fractional distillation ordinarily, but can, however, be removed in the pre-fermentation stage if desired. Data are not yet available for an accurate evaluation of the process.

A plant for producing alcohol from waste sulfite pulping liquor has been built recently with Federal funds at Bellingham, Washington, by the Puget Sound Pulp and Timber Company, with advice and technical assistance from the U. S. Forest Service. It is expected to produce about 2 million gallons of alcohol per year. First operation began in March 1945, but data on operations or costs are not yet available.

Synthetic Alcohol

In order to evaluate agricultural materials (which require fermentation) properly, as sources of industrial alcohol, attention should be paid to competing sources of alcohol which now represent lower-cost operation.

Alcohol can be produced by synthesis from certain gases, particularly ethylene. Ethylene occurs in natural gas and in the waste gases from petroleum refining. A simple scrubbing of the gas with concentrated sulfuric acid under pressure produces ethyl hydrogen sulfate, which in turn is easily hydrolyzed to ethyl alcohol. The sulfuric acid may be regenerated for reuse, or recovered as ammonium sulfate. The principal problem lies in the recovery or utilization of the byproduct acid. Recent developments in vapor phase hydrolysis have simplified the sulfuric acid recovery problem. Comparatively large amounts of ethylene contained in waste refinery gases are now unutilized, so that a source of large quantities of alcohol exists.. One limitation is presented by the required capital investment, which is higher than the similar requirement for fermentation alcohol plants. However, lower raw material and operation costs considerably offset the initial disadvantage.

Synthesis of alcohol from other gases is possible. Acetylene gas is available in some amounts from waste calcium carbide, and commercial production of ethyl compounds or of acetic acid is possible by oxidizing the acetylene to acetaldehyde, with appropriate reduction (or oxidation, in the case of acetic acid). This process is understood to be now used in Canada (at Shawinigan Falls) and at Niagara Falls, New York to produce acetic acid, but not to produce alcohol. Esters such as ethyl acetate may be made direct, without preliminary recovery of alcohol as such.

The synthetic alcohol industry has made a tremendous advance in the United States, as shown in table 8 following. Originally employed by the Carbide and Chemicals Company on natural gas at Charleston, West Virginia, about 1926, a second plant was soon started (1933) at Whiting, Indiana, by this same company, utilizing waste gas from the adjoining petroleum refinery of the Standard Oil Company of Indiana. Later a plant was built at Texas City, Texas (1940), also in conjunction with a petroleum refining operation. A new plant has (1943) been built at Baton Rouge, Louisiana, to use ethylene gas derived from the petroleum refining plants of the Standard Oil Company of Louisiana. Since the above companies now are heavily committed to synthetic rubber production, and since synthetic alcohol has not been usually employed heretofore for purposes which might include human internal use, practically all of this alcohol is used for synthetic rubber or munitions at present. (The rubber plant of the Koppers United Company at Kobuta, Pennsylvania, was planned to utilize alcohol from the Charleston plant.)

The proportionate production of synthetic industrial alcohol, principally from petroleum refinery waste gas, is shown in the following table:

Table 8.- Trends in industrial alcohol production from various raw material sources[1]

Source	Fiscal year											
	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942[2]	1943[3]	1944[3]
	Percent											
Molasses	83.0	83.4	85.5	76.1	75.7	73.1	67.6	68.5	70.4	68.1	30.8	24.7
Grain	4.1	6.3	2.7	7.0	8.4	9.1	7.7	5.7	5.9	9.1	56.4	65.0
Synthetic	9.7	7.3	9.7	16.0	15.2	17.6	23.8	25.1	23.4	21.4	12.8	10.3
Other	3.2	3.0	2.1	.9	.7	.2	.9	.7	.3	1.4	-	

[1] The general production trend is not accurately reflected by the percentages shown, for recent years. The actual trend is disguised by (a) current shortages of molasses, (b) increases in use of grain as raw material, (c) conversion of the entire beverage-alcohol industry temporarily to industrial-alcohol production for war purposes, and (d) large increases of total production occasioned by the war which exceed the relative increases in synthetic-alcohol production. Future production by synthesis may be from 60 to 70 percent of the usual annual pre-war consumption of industrial alcohol.

[2] Estimated from current reports, and based on production by Industrial Alcohol Plants only. Production of additional quantities of alcohol in beverage distilleries is not included. If included, the synthetic percentage is 16.8.

[3] War Production Board estimates for calendar year, based on all alcohol produced in distilleries and alcohol plants.

Alcohol is also formed or recovered in chemical operations such as ethyl cellulose manufacture (at Hopewell, Virginia) and methanol synthesis (at Belle, West Virginia). However, present recoveries from these sources are negligible.

A hitherto untapped source of alcohol lies in high-pressure synthesis from carbon dioxide. Methanol (so-called wood alcohol) is now made extensively by catalytic synthesis from carbon monoxide, plus hydrogen, under high-pressure conditions. Carbon dioxide, which is available in large amounts is easily reduced to carbon monoxide. Variations of flow constants, or substitution of other gases for carbon monoxide, will yield alcohols (or derivatives) higher in the series than methanol, such as ethyl or butyl alcohols. Although tried abroad, particularly in Germany and France, and although a number of patents are extant, there has been little inducement to make ethanol by this method, because of the competition from other sources. However, the possibility exists, and visualization of the future production of alcohol for industrial or fuel purposes from relatively expensive farm products must be limited by the prospect of cheap alcohol from chemical sources.

Financial Aspects

Plant Costs

Since all fermentation alcohol plants differ in some respects from each other, no accurate, generally applicable basic investment cost can be formulated, and no standard production technique exists. In general, plants utilizing molasses apply a much simpler process and require less equipment than do grain plants, since grain handling and byproduct feed recovery operations are omitted and since steam requirements are less. Under normal price scales, the cost of a plant using molasses may be considered as requiring a capital investment approximating $50.00 per wine gallon of daily output of 190 proof alcohol. Actual variation in such investment may run from $35.00 per gallon of output, for a very cheap plant, to $75.00 or more for a modern, well-built plant fully equipped with instruments and labor-saving facilities.

Grain-using industrial alcohol plants, or distilled spirits plants, will cost from $50.00 to $150.00 per gallon on the same basis. The lower figure represents old-style plants with wooden open-top fermenters, very simple grain-milling equipment, open mash-tub (atmospheric-pressure) cooking, and recovery of spent grain screenings only. The higher figure represents a modern distilled spirits plant featuring controlled milling with grain degermination, pressure cooking, recovery of high-grade alcohol in high concentration, and complete recovery and sale of fermentation byproducts. Such a plant would be fully equipped with instruments, would be largely automatic in operation, and would have extensive control and research laboratories. A satisfactory industrial alcohol plant probably could be built under normal conditions for approximately $100.00 per gallon of daily output. These costs may be lowered in future years.

The respective costs of plant facilities required for molasses and grain processing and additional investment necessary for different steps of byproduct recovery, are indicated (approximately) in table 9. (See appendix.)

Cost of Producing Alcohol

The cost of producing alcohol depends upon the location of the manufacturing plant; the design, type, and degree of modernization of equipment; the kind of raw material used; the price paid for the raw material; the relative labor costs represented; the scale of production; and the total investment. It should be emphasized that there is no such thing as a fixed "alcohol cost," for it will vary between plants and even from day to day in the same plant. The cost has fluctuated widely during recent years. It was estimated that, under the conditions which existed about 1938, the plant-operating (conversion) cost of producing a gallon of 95-percent alcohol from blackstrap cane molasses might be as low as 3 to 4 cents per gallon (exclusive of raw material) for a unit operating at the highest efficiency and producing from 20,000 to 30,000 gallons of alcohol per day. Normally, for smaller or less efficient operations, such cost may exceed 6 cents. With blackstrap molasses at the ordinary, pre-war price of 5 cents per gallon, and with a yield of 1 gallon of 99.5 percent alcohol from 2-1/2 gallons of molasses, the operating and raw material costs would approximate 18-1/2 cents per gallon of alcohol, under good operating conditions.[a]

The operating (conversion) cost for producing alcohol from corn in manufacturing plants of 20,000 to 30,000 gallons daily capacity was estimated[a] to be between 7.5 and 13.0 cents per gallon, exclusive of malt cost, which runs from 2 to 5 cents per gallon of alcohol produced. Assuming a corn price of 45 cents per bushel delivered at plant (a usual pre-war price for distilling grade), a malt price of $1.00 per (34-pound) bushel, the use of 8 percent malt, a value of 12 cents for the byproduct from each bushel of grain, and a yield of 2.50 gallons of 95-percent alcohol per bushel, the operating and raw material costs of alcohol from corn can be estimated at approximately 30 to 32 cents per gallon. These costs do not include sales expense or freight, cost of subsequent denaturing, or the cost of distribution. Profits to the producer and retailer must be added to these costs to determine the price per gallon to the consumer. These figures are merely typical and will vary with conditions. Reported figures have varied greatly, particularly since some operators separate certain overhead, management, and supervision items from direct plant costs, so that lower "conversion" costs are indicated.

A general itemization of processing costs for a complete grain-using plant is tentatively shown in table 10. Variations from these cost figures may be expected, and the net final cost of the alcohol may vary 5 cents or more per gallon from the values shown, in individual plants. (Table in appendix.)

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[a] Misc. Pub. USDA, No. 327 (1938) p. 52.

Relative Costs of Alcohol from Different Farm Crops

The yield of alcohol obtainable from the various farm crops depends upon the character of the material and the efficiency of operation. Properly selected, treated, and fermented carbohydrate materials, upon distillation, may be expected to yield alcohol at costs about as presented in table 11. (Since the materials commonly used for industrial alcohol production are not of the highest market grades, an average rather than a high fermentable-matter content is assumed in this computation.)

Table 11.- Estimated relative costs of alcohol from certain farm crops in comparison with waste molasses (Basis, 100 wine gallons of 95-percent alcohol produced)

Raw material	Amount required (units)	Price per unit (delivered)	Raw material cost	Assumed processing cost 1/	Total cost	Estimated credit for byproducts 2/	Net cost of 100 gals. alcohol 3/
				Dollars			
Molasses (blackstrap)	250.0 gals.	0.05 gal.	12.50	6.00	18.50	0.50	18.00
Apples	7.0 tons	5.00 ton	35.00	9.50	44.50	5.00	39.50
Corn	40.0 bu.	.40 bu.	16.00	18.00	34.00	6.50	27.50
Grain sorghum	45.0 bu.	.35 bu.	15.75	18.00	33.75	4.50	29.25
Potatoes	145.0 bu.	.10 bu.	14.50	13.00	27.50	1.50	26.00
Sweetpotatoes	100.0 bu.	.15 bu.	15.00	12.00	27.00	1.50	25.50
Sugar beets	4.52 tons	5.00 ton	22.60	9.00	31.60	3.60	28.00
Wheat (soft)	40.0 bu.	.70 bu.	28.00	18.00	46.00	6.10	39.90

1/ These costs represent the summation of a great many variables, and will differ for each plant. Malt costs are included for starchy materials, but profit is omitted.

2/ Fusel oil and byproduct feed (distillers dried grains) only. The feed values will vary with changes in cost of the original raw materials.

3/ These figures are the net resultant of many variables, and must be considered as being tentative. However, the figures shown probably reflect the relative order of cost for the raw materials and prices used. In order to produce alcohol from farm crops at a cost equal to that of molasses alcohol, the prices paid for the various raw materials must be correspondingly reduced, unless processing costs are cut or byproduct values are increased.

This table indirectly indicates the approximate price (for normal times) at which the various crops must be obtained if they are to compete in alcohol production. Although all the respective alcohol costs shown are greater than the molasses alcohol used as a basis, it may be seen that the prices at which the raw materials are computed are below the usual market prices, and in the case of potatoes, for example, represent cull values only. The figures in this table do not include differences in transportation costs and general items not ordinarily included as processing costs. They are based merely on the relative carbohydrate content of the particular commodity plus an estimated conversion cost, with estimated byproduct credit allowances. Five cents a gallon is taken as a fair price for molasses, in comparison with the other potential alcohol sources. (War prices of blackstrap molasses reached 19 cents per gallon, placing this material temporarily at a disadvantage with corn, at around 85 cents per bushel.)

Corporate Financing and Control

Alcohol plants are ordinarily financed by private capital and, as a rule, the industrial alcohol plants have a more or less effective tie-in with other industries. For example, synthetic alcohol is produced in plants subsidiary to the petroleum refining industry, or as byproducts of certain cellulose ester or other industries. One of the two largest fermentation industrial alcohol production groups is understood to be owned indirectly by the Standard Oil Company of New Jersey.[a] One large plant is owned by E. I. du Pont de Nemours and Company; other single plants are owned by the Merrimac Chemical Company, and the Pennsylvania Sugar Company. There are only a few wholly independent operations of significant size. As stated previously, a certain group of industrial plants are actually a part of the beverage alcohol industry.

It was recently estimated[a] that 80 percent of pre-war normal industrial alcohol production came from five corporate groups, as follows:

	Percent
Carbide and Carbon Chemicals Corporation (synthetic)........	20
Publicker Commercial Alcohol Company	18
U. S. Industrial Chemicals, Incorporated.....................	17
E. I. du Pont de Nemours and Company	13
Commercial Solvents Corporation	12
Miscellaneous plants	20

In contrast to the industrial alcohol industry, the beverage alcohol industry in past years has consisted generally of a large number of small, independently owned plants. However, in the past few years there has been a trend toward the consolidation of these small plants in the hands of about four large

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[a] Hearings, S. Res. 227, (Gillette Committee) Part II, pp. 810-17 (1942). Statement of Thurman W. Arnold, Assistant Attorney General.

corporations (Seagram, National, Hiram Walker, and Schenley)[a]. Such consolidation may bring about more uniformity of equipment, design, methods, and products in the beverage industry, and eventually may cause elimination of higher production cost plants. The beverage industry, while producing alcohol, is not primarily interested in the sale of alcohol as such. Its interest lies in producing, continuously and consistently, various alcoholic beverages, each of uniform flavor and palatability, largely in accordance with established trade names or brands. Since brand character may be adhered to rather generally, regardless of possible technical changes or economies otherwise possible, this may tend to perpetuate operations in certain older, semi-obsolete plants, if brand characteristics depend on existing operation factors in such plants.

A few new industrial alcohol plants have resulted from the war emergency, as shown heretofore. The three larger plants, which began operation early in 1944, were partly financed by Government funds, but will be operated by individual firms in two instances, and by a large beverage alcohol firm (National Distillers) in the other. Several more plants came into operation recently, mostly converted breweries or wineries. However, the Government has made loans to a number of groups or companies, to cover equipment changes, more particularly on feed-recovery equipment. Some processing equipment has also been allocated to eliminate production-flow bottlenecks.

Patent Situation

Owing to the age of the industry, any basic patents on the alcoholic fermentation process have expired. Patents on specialized equipment are usually owned by the equipment manufacturers, and purchase of such equipment ordinarily carries with it the right of use. Patents are still in effect on anhydrous alcohol production methods, but some of these will expire soon. The most effective group of patents covers the production of synthetic alcohol. It is not considered that the patent situation presents any real obstacle to operation or expansion of the industry. During the war, originators of certain processing improvements, that later may be patented, have allowed free use by all, as a patriotic gesture.

Present Status of Methods for Producing Alcohol from Agricultural Products

Technological progress

In the past, both the distilled spirits and industrial alcohol industries have employed certain common, basic, conventional processing steps, regardless of individual plant variations due to the particular equipment used. The conventional alcohol production process in both industries has consisted of

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[a] Report of Congressional Investigation Committee, in Congressional Record, August 7, 1944, pp. 6808-12. Some plant purchases may have been effected for the immediate purpose of acquiring existing whiskey stocks during the shortage.

a series of batch operations, so arranged that a continuous flow of final product is secured. In the distilled spirits industry experimentation with new or radically different methods had not progressed, for reasons previously explained. In the more recently built plants, such cost-saving improvements as were possible through increased plant efficiency were accepted, but, until recently, very few changes were made in the old-line plants.

In the production of industrial alcohol the past situation had made it necessary to secure highest yields at lowest cost. Latitude in operation to achieve this end was permissible, since good distillation equipment could usually produce a satisfactory product, somewhat regardless of the original material or process factors used. In this industry changes were limited, however, by restricted profits due to the pre-war market situation and hesitancy to increase investments. Only in the last few years have any considerable changes been adopted.

Since a continuous flow of product is desired, the ideal process would be one that is based on a continuous flow or progression of the materials through the plant, rather than employment of a series of successive batch operations. Significant economies could thus be achieved. With such a process, the entire plant might be reduced to a continuous pipe line in which the successive changes would be wrought on the raw and mashed material while in continuous flow. Within the past three years several significant improvements leading in this direction have been adopted commercially. These originated in the beverage industry, since grain was involved, so that it was more particularly a problem of that industry. One of these improvements is the (Seagram)[a] continuous cooking method, in which a premixed slurry of grain is continuously cooked by a steam jet, the cooked material is continuously cooled, and malt is continuously added to the moving material. The conversion of starch to sugar takes place largely in the fermenter. This method eliminates hold-up of flow due to inadequate batch-cooking equipment, and reduces the cooking equipment requirements significantly. It is being adopted to a considerable extent in both industries because of simplicity of operation, saving of time and labor, and the relatively smaller amount of equipment required. There has also been partially successful experimentation with the continuous development of yeast. Since the grinding of grain has always been done continuously, it seems that alcohol production can now be made continuous through all stages up to actual fermentation.

There has been considerable experimentation on continuous fermentation, and while the difficulties have precluded successful operation thus far, it is quite possible that this problem may be solved. Semi-continuous methods, conducting fermentation in successive stages, have been commercially employed. Since the succeeding alcohol distillation and slop-recovery steps already are continuous-flow processes, the successful operation of the continuous fermentation step would permit the entire process to actually reach the pipe-line

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[a] Thus frequently named, but apparently originating in Russia (See Hearings, S. R. 227, Gillette Committee, Vol. 6, p. 1741.) 1943.

ideal mentioned above. With these improvements, obviating the need for batch pressure cookers, large fermenting tanks, and general storage tanks, the future alcohol processing plant may be reduced to relatively smaller space and simpler equipment.

Much information has been developed recently on the action of the enzyme systems used in converting starch to fermentable sugar. Malt requirements (except for distilled spirits production) can be reduced by the supplemental use of mold enzymes in varying amounts; this is desirable because malt is relatively more expensive. (In the case of beverage spirits, any dependence on malt for flavor characteristics would prevent such malt savings, while the use of molds may introduce undesirable taste and odor in the product.) The use of enzymes naturally existing in certain grains, particularly wheat, to replace part of the malt has been shown to be industrially possible.

This starch-conversion step of the alcohol manufacturing process represents a promising field for further experimentation. In converting starch to sugars that can be fermented by yeast, some dextrins usually are formed instead of equivalent sugar. These dextrins eventually are broken down and fermented to a considerable degree, but a prolonged fermentation period is required. During this final period, while the dextrins are being broken down slowly (and never completely), the yeast activity falls off because most of the readily fermentable materials are used up, since sugar fermentation proceeds easily and rapidly. A sluggish stage occurs, in which contaminating bacteria that usually are present in the mash have an opportunity to multiply and to cause the formation of organic acids at the expense of alcohol. A point is reached where acid formation may equal the alcohol formation from the slowly decomposing dextrins. The use of a saccharifying method or agent that would accomplish quick and complete starch hydrolysis and avoid dextrin formation, thus permitting quick and complete fermentation, would increase yields and efficiency, decrease equipment requirements, and reduce chances of bacterial contamination. In present methods, about 10 to 15 percent of the original starch escapes yeast fermentation. The enzymes of malt consist of a variable proportion of alpha and beta amylase, but since the starch in grain is a mixture of two main types of molecules, a portion of which are not wholly decomposed to sugar by beta amylase, some alpha amylase and perhaps other enzymes are also required. Alpha amylase is present in relatively high amounts in some mold and bacterial enzymes, but generally malt is deficient in the requisite quantities. Grain enzymes consist principally of beta amylase.

The problem is further complicated by the fact that "liquefaction" of starch to reduce the viscosity of the uncooked or partially cooked mash, is an essential part of the conversion process. Alpha amylase is a better liquefying agent, but the liquefaction action may result in dextrin formation. Seemingly a mixture of enzymes from various sources may be superior to malt alone, for higher alcohol yields. Much recent experimentation has been done in this general field of enzyme action.

Considerable data have been accumulated on the effect of pH, temperature, and concentration on processing time and alcohol yield, and the modern tendency is to conduct the fermentation on increasingly concentrated mashes in order to save steam.

There is less development to be expected in the distillation step, since this operation has always been based largely on sound engineering principles, at least so far as modern equipment is concerned. The quality of product from most equipment in use is satisfactory; hence, innovations are principally directed toward savings in process steam and water. Considerable economies in use of these are possible. Water may pass in sequence through successive condensers, and steam may be re-used by application of the "effect" principles as used in multiple effect evaporation.

In the manufacture of anhydrous alcohol there have been important developments, but data are not available as to which of the six methods commercially perfected is the most economical. The original method was based on the use of benzene to form an azeotropic mixture with the alcohol and water. In the more recently developed "Drawinol" method, the benzene was substituted by trichloroethylene. Alkaline diethylene glycol is also employed in another type of process. A new method involves the use of ethyl ether, under pressure, as the water-separating agent. Other methods have accomplished the removal of the last traces of water from the alcohol by use of solid dehydrating agents such as anhydrous calcium acetate, aluminum oxide, copper sulfate, etc. There is a patented method in which a reaction between added ether and the contaminating water produces additional ethyl alcohol without further distillation, but this is not known to have been employed commercially. Seven plants are now equipped for anhydrous alcohol production in the United States.

Attempts have been made to re-use the yeast for successive fermentations. Since the yeast cells are propagated at the expense of carbohydrate, such re-use should increase alcohol yields by an equivalent degree. In ordinary practice, the yeast is not re-used in the United States, but has been used in foreign countries (Melle process). In the re-use process, the yeast is allowed to settle out (as is done with brewery processing) or is centrifuged from the fermented beer. In the case of whole-grain mashes, the yeast is contaminated by the unfermented grain residue. In the case of molasses or granular wheat flour, a relatively clear beer is handled and the yeast separation becomes relatively simple. Chief hazards of re-use would lie in the difficulties of preventing contamination of the yeast by other vegetable cells, and in maintaining good viability in the yeast cells. Failure in either of these points would entail lowered alcohol yields. The process currently is being employed commercially in the production of alcohol from waste sulfite liquor.

Byproducts

The principal byproducts from fermentation are carbon dioxide and fusel oil, and--in the case of grains--corn oil and byproduct feed (distillers' grains).

Much recent work has been done on recovery of waste stillage. Obtaining greater values from the waste unfermented material would decrease the manufacturing cost of the alcohol, particularly in grain-using plants. In past years this possibility was rather extensively ignored, especially in the industrial alcohol industry. So far as known, only one molasses-using alcohol plant recovered values from the stillage, and this was done principally because of stream pollution laws, as the recovery expense probably exceeded the returns. The beverage alcohol industry, however, made some attempt to recover grain residues as feed, either by direct feeding of stillage to cattle or hogs or by screening the solids from the stillage and drying them for sale, with or without further recovery of the filtrate or thin stillage. Recovery of the latter represented a complete-evaporation problem and was not economic at most of the older and smaller plants. The modern distilleries built in recent years are based on complete stillage recovery, although even in these it usually has been impossible to recover 100 percent of the waste material. With the growing realization of the value of the vitamins, as well as that of proteins in the stillage, and with more specialized use of distillers "grains" in feeding, has come an increase in the quantity, quality, and diversity of byproduct materials marketed. The stillage is high in water-soluble vitamin content, and, in the case of corn, some carotene, precursor of vitamin A, is present. Bauernfeind and Boruff[a] give the following vitamin values for corn stillage:

Vitamin or carotenoid	In solubles	In dark grain	In light grain
		Micrograms per gram	
Thiamin (B_1)	6 - 10	3 - 4	1 - 2
Riboflavin (B_2)	15 - 30	7 - 10	2 - 3
Pantothenic acid	21 - 36	10 - 13	3 - 4
Niacin	90 - 160	40 - 90	15 - 30
Pyridoxine (B_6)	8 - 10	---	---
Biotin	0.4 - 0.5	0.18-0.22	0.04
Choline	6000 - 7000	4000 - 5000	1500 - 2000
Carotene	0.8	1.0 - 1.2	1.8
P-amino benzoic acid	9 - 10	---	---
Folic acid	4.0	---	---
Zeaxanthol	6.5 - 8.8	7.5 - 8.3	8.0
Cryptoxanthol	3.8	5.0 - 5.6	5.1

Recently, experiments have been made on the refermentation of the stillage to raise the vitamin values. Additional developments in this field may be anticipated. Not much alcohol is recovered in this supplementary fermentation, but vitamin contents are greatly increased.

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[a] Fermentation Byproducts as Animal Feeds. American Miller and Processor Mag., January 1944, pp. 182-3; Part II, same, February 1944, pp. 53-4; Part III, same, March 1944, pp. 50-52. See also J.I.E.C. January 1944, pp. 76-8.

Recently, shortages of feed materials have stimulated efforts toward more complete recovery of wastes in alcohol plants where this is economically feasible, and much equipment has been installed to accomplish this. Experiments on the separation and recovery of special protein fractions have been tried. In one instance, precipitation by use of chemical agents has shown promise. It may be anticipated that further development will be made in byproduct recovery in alcohol manufacture. With any great future use of surplus grain as motor fuel (as an alcohol-gasoline blend), the recovery of equivalent protein values from the grain thus removed from normal markets probably would be highly significant.

In the case of the unfermented residual portion of the grain, considerable latitude exists as to method or form of use, and a potential market for practically any amount likely to be produced can be foreseen. The material can be fed to animals direct, as whole stillage, or it can be recovered in fractions of different composition which can be fed direct, or dried and shipped. Commercial dried products now include:

> Distillers' dried grains--representing the dried solids removed from the stillage by simple screening. (So-called "Light" grains)
>
> Distillers' dried grains with solubles--the product of more or less complete recovery of the stillage in two stages, the screenings (light grains) being coated with sirup obtained by subsequent evaporation of the liquid from the screens (thin stillage) and dried further, or the two portions thus obtained being mixed after drying separately.
>
> Semi-dried solubles--semi-solid distillers' solubles, obtained by evaporating thin stillage to a sirup.
>
> Dried distillers' solubles--obtained by evaporation and drying of sirup from the thin stillage by drum dryers, spray dryers or other means.

Each of the above classifications is further identified by the principal grain origin, as corn, wheat, rye, etc.

> High-vitamin concentrates--obtained by special recovery methods or by re-inoculation and re-fermentation of the stillage.
>
> Special protein fractions--obtained by protein precipitation methods.

The last four types represent a new trend in the industry toward the development of specialized products. Potential profits in this field may exceed the profits from alcohol production, with a marked effect on alcohol production costs.

The situation in February 1943, with regard to recovery of stillage byproducts in distilleries or industrial alcohol plants using grain, was as follows:

22 plants wasted stillage completely.
42 plants used the whole stillage as feed, either directly or through sale.
33 plants screened out the solids and dried these for sale, wasting the thin stillage.
20 plants screened and dried the solids and used the liquid portion in direct feeding to a limited extent.
14 plants recovered the whole stillage in dry form as various products.
(at least 9 plants were equipped for separate recovery of thin stillage as dried solubles.)

Since the plants making the more effective recovery of stillage represented the larger and more modern portions of the industry, the actual recovery was greater than the apparent plant figures would indicate.

Based on the assumed potential byproduct recovery calculated from the original grain used during the month, which amounted to 59,840 tons, the actual dry feed produced was 32,000 tons, equivalent to 53.6 percent recovery, as dry material for sale. An estimated 17,304 tons, or 29 percent was lost. The balance was more or less effectively used in direct feeding. As considerable equipment for recovery has subsequently been installed, the situation as to possible recovery is now greatly improved. Further equipment additions have been approved by the War Production Board, which should result in approximately total recovery. Much of this was in operation by late 1944. Production of dry feed for October 1943 amounted to 33,141 tons (some few companies not reporting). This production was divided among the various classifications as follows: Light grains 58.3 percent, dark grains, 36.9 percent, dried solubles 4.8 percent.

Production of dried distillers' grains in 1944 amounted to 275,436 tons of dried light grains, 177,427 tons of dark grains, and 32,507 tons of solubles, or a total of 485,370 tons. This represents only about 6.3 pounds recovered per bushel of grain used during the year (74 plants reporting). Considerable apparent loss occurs in the use of granular flour. Obviously, the byproducts are recovered, in such case, at the flour mill, and do not appear as distillery production. Also, the use of wheat instead of corn actually reduces the amount recoverable, since much of the present recovery still is limited to screened solids only, and wheat has less screenables and more solubles than corn. Plant mashing capacities may be reduced when wheat is substituted for corn.

The recovery of carbon dioxide represents a potential source of income only within the limits of possible markets. Several methods of purification exist. About a pound of CO_2 is set free for each pound of alcohol produced. However, under existing recovery methods only about 70 percent of this is economically recoverable. Market situations in the past have tended to restrict over-all commercial recovery, so that perhaps only 40 percent or less of the original gas produced could be utilized, because of seasonal fluctuations of demand. As the time of storage of solid CO_2 is limited, it is not possible to store reserves for the period of heavy demand in mid-summer; in winter the demand drops off. Liquid gas stored in cylinders is free from this limitation but is controlled by the relatively high storage expense represented by the cylinders. Values of CO_2 recovery, over-all, are not likely to exceed a credit of 4.7 cents per gallon for limited operation periods, (based on sale prices of the gas), and the yearly average can be expected to net only about 2 cents per gallon of the alcohol produced.[a] Considering the cost of producing the gas from coal, these values are high, and could hardly be realized.

The extent of the potential market can not be stated accurately. Distillery gas must compete with CO_2 from stack gases, natural gas wells, etc., as well as with mechanical and ice refrigeration. Both liquid carbon dioxide (compressed in cylinders) and solid carbon dioxide (dry ice) constitute specialty products. The largest apparent market available for further development is in refrigeration of freight cars in transit. Production of urea is a further possibility. About 14 alcohol plants now recover CO_2 or sell the gas to a subsidiary for recovery. In several instances the gas is used at the plant in other operations, and thus is not marketed. Approximately 22 percent of the total CO_2 market may be now supplied from alcohol plants under wartime conditions.

Fusel oil is produced in amounts of 1 to 5 gallons per thousand gallons of alcohol produced. The actual production depends upon the raw material used, the conditions of fermentation, and the operation of the alcohol rectifying equipment. On the average, the several raw materials might produce fusel oil and alcohol in the following ratios:

Blackstrap molasses	4 to 5 gals. per 1,000 gals. alcohol
High-test molasses	1 to 3 " " " " "
Corn	4 to 5 " " " " "
Degerminated corn	2.5 to 3.0 " " " " "
Wheat	2.0 to 3.0 " " " " "
Rye	2.0 to 4.0 " " " " "

Fusel oil is used as a nitrated cotton solvent and as a source of amyl compounds. It is recovered at practically all industrial alcohol plants, but not by many distilleries, since it is only recovered when "high wines" are rectified.

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[a] U.S.D.A. Miscel. Pub. 327 (1938)

Fusel oil represents a mixture of amyl, iso-amyl, N-propyl, and iso-butyl alcohols, and various esters. Typical analyses of crude fusel oil by various investigators are reported as follows:

Constituent	Corn	Fusel Oil From Molasses	Fusel Oil From Potatoes	Rye
		Percent	Percent	
Iso-propyl alcohol	--	0.6		
N-propyl alcohol	20.4 to 11.7	24.3	6.85	[illegible]
Iso-butyl alcohol	23.9 to 12.2	7.4	24,35	15.7
N-butyl alcohol	--	8.1		
d-amyl alcohol	14.6 to 23.4)	55.3	68.76	79.8
Iso-amyl alcohol	36.3 to 59.7)			
N-amyl alcohol	--	4.3		
Undetermined	4.8 to 3.0	--	0.04	6.5

These compounds seem to be derived largely from protein degradation (amino acids) and do not necessarily mean loss of carbohydrate. The crude fusel oil is washed free of ethyl alcohol, and is either sold direct or redistilled into fractions to meet appropriate specifications. The value of the oil is usually greater than that of the same quantity of alcohol. Generally, fusel oil is not recovered in distilled spirits production unless modern distillation equipment is available.

Corn oil may be recovered from corn germs removed from the grain before fermentation. Only one or two alcohol (beverage) plants employed degermination of corn and recovered corn oil in 1943, although the three large midwest industrial alcohol plants recently completed contemplate such recovery. Most of the corn oil now produced is a byproduct of the cornstarch industry. About 1 to 1.2 pounds of oil are secured from a bushel of corn. Degermination or oil extraction of other grains before fermentation is not practiced. Removal of the germ before distillation of corn does not reduce alcohol yields per bushel of original grain; it might be practiced more generally if profitable, but the market situation will be dominated by the far larger production of corn oil in the cornstarch industry.

Possible Post-War Situation in the Alcohol Industry

It is impossible to predict accurately the situation that will develop following the war. It is, however, possible to make certain assumptions and therefrom to formulate conclusions, at least as to trends. Thus, it may be expected that the beverage alcohol industry will revert promptly to distilled spirits production at the earliest opportunity, if legally possible. In order that all producers may have equal advantage in building up stocks for aging, such conversion may be expected to be immediate, throughout the whole industry generally, and to be complete--that is, to practically full capacity of every plant. Further production of industrial alcohol by this industry will cease in such event, except for some production of pure alcohol for whiskey blending, unless a quota arrangement is set up whereby a certain continuing production of industrial alcohol for general use is maintained to supplement the efforts of the true industrial alcohol industry to meet the early post-war requirements. It is possible that such assistance will be needed. The return of this industry, in toto, to distilled spirits production means a potential reduction of ±300 million wine gallons annually from current industrial alcohol production.

In this post-war period, it may be anticipated that there will be an increased requirement of alcohol for usual industrial purposes above the pre-war normal consumption. This is likely to be accentuated in the first year or so following the cessation of war, and to continue decreasingly through the period during which accumulated shortages of civilian commodities would be gradually taken care of. These industrial general-use requirements may reach 150-200 million gallons annually at peak, gradually decreasing, at an accelerating rate, to perhaps a normal consumption of 125 million gallons after the first large demands are satisfied. In addition, there may be an increased use of pure alcohol for blending of beverages, amounting to perhaps 25 million gallons or more per year at peak and levelling off to an assumed 13 million gallons normal rate. Governmental, scientific, and hospital requirements for tax-free use will probably continue at slightly more than pre-war rates (2,000,000 to 5,000,000 gallons as a maximum).

In addition to the usual needs for industrial alcohol, the war-born synthetic rubber industry may require large amounts of alcohol for a period of several years. Consumption of alcohol for synthetic rubber production passed 125 million gallons in 1943, increased to 330 million in 1944, and is expected to total 330-360 million in 1945, under the present synthetic rubber program. During 1943, about 75 percent of the synthetic rubber was being made indirectly from alcohol.

It may be assumed for purposes of this discussion that the use of alcohol for rubber in the amount of 330 million gallons annually will continue until the end of the war with Japan, and perhaps a few years thereafter, but that such consumption will gradually diminish if and when importation of natural rubber is resumed. There is not sufficient available information on the natural rubber situation to permit the drawing of definite conclusions. The extent of damage sustained by rubber plantations in Java, etc., the post-war labor situation, the competitive production of synthetic alcohol from petroleum, and the existence or operation of post-war international agreements are unknown factors; so the post-war consumption of alcohol will obviously depend on many contingencies. However, to permit computation, the eventual, continuing use of alcohol for synthetic rubber might be estimated at 125 million gallons, assuming plant operation at one-third capacity and production prorated as at present to different processes.

Thus, while the actual amounts cannot be definitely predicted, the total post-war industrial alcohol requirements may be assumed to be somewhere between the former usual 100-million rate and a short period peak rate of 580 million. Following the early readjustment period a high consumption rate may continue, averaging perhaps 350 million for a period of years before dropping eventually to perhaps a 265-million rate (140 million, exclusive of rubber or fuel use). The trends are shown in the graph on page 46a (Figure 1) which is self-explanatory. In this graph, past known production is contrasted with the assumptions made here. It is believed that the various curve trends shown therein are reasonable deductions from the current situation, although the actual year designations may have to be suitably shifted, with progress of events, to encompass significant changes in the picture. Any such changes will, of course, affect the slopes of the curves. This figure is inserted mainly to illustrate graphically the points discussed herein, and is not to be construed as a true or exact statement of the future situation on any fixed date. Data are shown in proof gallons for convenience in comparing with alcohol statistics. (One wine gallon of 190°-proof alcohol represents 1.9 proof gallons.)

As shown in table 6, the anticipated production capacity of the real producing part of the future industrial alcohol industry (including plants not yet in production) will range from 325 to 445 million gallons annually, or up to 50 percent of the assumed consumption requirements of the early post-war period. The potential situation may be estimated as shown in table 12. This table indicates that, if all restrictions are immediately removed following the end of the war so that all plants can promptly revert to pre-war status, a total consumer demand of 830 to 880 million gallons may exist (for both beverage and industrial purposes), with about 600 to 755 million gallons of production capacity available. An estimated 380 to 450 million gallons of the required amount will probably have to come from grain. This higher amount about equals the present maximum alcohol production capacity of all existing grain type plants. Any deficit would have to be made up by importation or from unconsidered sources (if such sources can be found), or else some consumer demand must go unsatisfied. The bulk of the required alcohol (60.0 to 64.0 percent) must come from grain. To get this much, it will be necessary to utilize the midwest industrial (grain-type) alcohol plants and the beverage spirit plants fully. However, after the first rush demand is met and stocks of distilled spirits begin to accumulate, the situation may ease off, especially if synthetic rubber requirements are lessened. Within a few more years, when accumulated industrial-alcohol demands are satisfied and distilled spirits stocks are up to par, the ordinary consumption requirements are likely to be less than the combined producing capacities of the two industries. At this point, prices should fall and competition become keener, and, thereupon, the less economic plants are likely to be forced out of production. Among these, the Eastern molasses plants which have been converted to grain use in varying degrees, and the new midwestern grain-using plants will constitute a notable group. Consequently it may be reasoned that pressure will be exerted at such time to keep these plants in operation on some basis, depending upon the acuteness of the situation. About twelve plants, representing perhaps 110 to 140 million gallons annual capacity, are particularly likely to be affected under such conditions.

Table 12.- Possible post-war situation for industrial alcohol and beverage alcohol (distilled spirits)

Purpose	Pre-war rate	Post-war requirements: Assumed immediate post-war rate	Post-war requirements: Assumed rate five years later
	(Wine gallons, in millions, per year)		
Industrial Alcohol			
For usual trade consumption	100	150 to 200	125
For tax-paid (principally beverage) use	12	25	13
For tax-free use	3	5	2
For synthetic rubber	--	330	125
Export	--	20	--
	115	530 to 580	265
Distilled Spirits	85	300	125
Total requirements	200	830 to 880	390
How requirements may be met			
Production capacity available to meet requirements (exclusive of butyl [illegible] production)	+450	600 to 755 (max)	580 (probable) to 705 (maximum)[a]
Probable importation	None	35	20
Available to meet requirements		635 to 790	600 to 725
Classification as to raw material			
From molasses	83	150 to 220	130 to 150
From grain	89	384 to 450	167 to 125
From synthetic processes	25	60 to 78	70 to 90
From miscellaneous sources	3	6 to 7	3 to 5
	200	600 to 755	370
Probable importation		35	20
		635 -- 790	390

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[a] Eliminating some less economic plants.

The post-war production of beverage spirits is likely to develop somewhat similarly to the situation that existed following repeal of the national Prohibition law in 1933, if the legal situation permits. However, in this earlier experience, stocks were very low, and only a few plants were in shape for immediate production. The quantities of spirits manufactured and of raw materials used, the speed of entry of plants into production, and the rapid rise of stocks, despite a huge accumulated consumer demand, are shown in table 2 (see appendix) and figure 1. At the present time (May 1945) about 130 grain distilleries are in active operation on industrial alcohol,from grain, (17 of these also operate as industrial alcohol plants) and can swing into distilled spirits production at a few hours' notice. An annual output capacity of 270 to 305 million gallons (95 percent or 190-proof equivalent) is represented by those plants. Consequently, the lag period previously experienced will probably not recur, and immediate full-rate production, utilizing certain farm crops in pre-war peak quantities, can be anticipated.

With later post-war decrease in alcohol demand, it may be assumed that competition will become keener in both industries; therefore, a number of less economic alcohol plants will eventually go out of operation unless they are extensively rebuilt and modernized. While individual plants in the beverage alcohol industry may be able to continue operations somewhat on the pre-war status, the industrial alcohol field is likely to be more highly competitive than ever before, since this greatly enlarged industry will face the constant possibility of invasion of its markets by beverage alcohol plants (which now know how to make industrial alcohol, and, in many instances, have essential equipment), as well as by new foreign alcohol producers. The solution will lie in the continuance of large markets. Obviously, the cheapest raw material will be used as far as is possible. This indicates the use of molasses, as alcohol from grain cannot yet compete in the field of industrial alcohol. Also, it must not be forgotten that synthetic alcohol production has increased from a former 25 million to a present 60 million gallons per year, (60 percent of pre-war industrial alcohol use). Post-war output capacity,under favorable conditions might go as high as 90 million gallons (or more) annually, or over 60 percent of anticipated total industrial alcohol requirements after the post-war peak, (excluding synthetic rubber).

Midwestern corn-using plants will have to consider the relative costs of shipping alcohol to points of use. These plants have the advantage of low freight costs to some industrial points, such as Chicago, St. Louis, and Kansas City, but are at a corresponding disadvantage as to eastern, southern, and western points where local production can take care of practically all demands. Normally, the area from the Sierra to the Allegheny Mountains, with the exception of the cities named, consumes little industrial alcohol (except as antifreeze). Pre-war alcohol production and consumption in different areas were estimated (Circa 1941?) as follows:[a]

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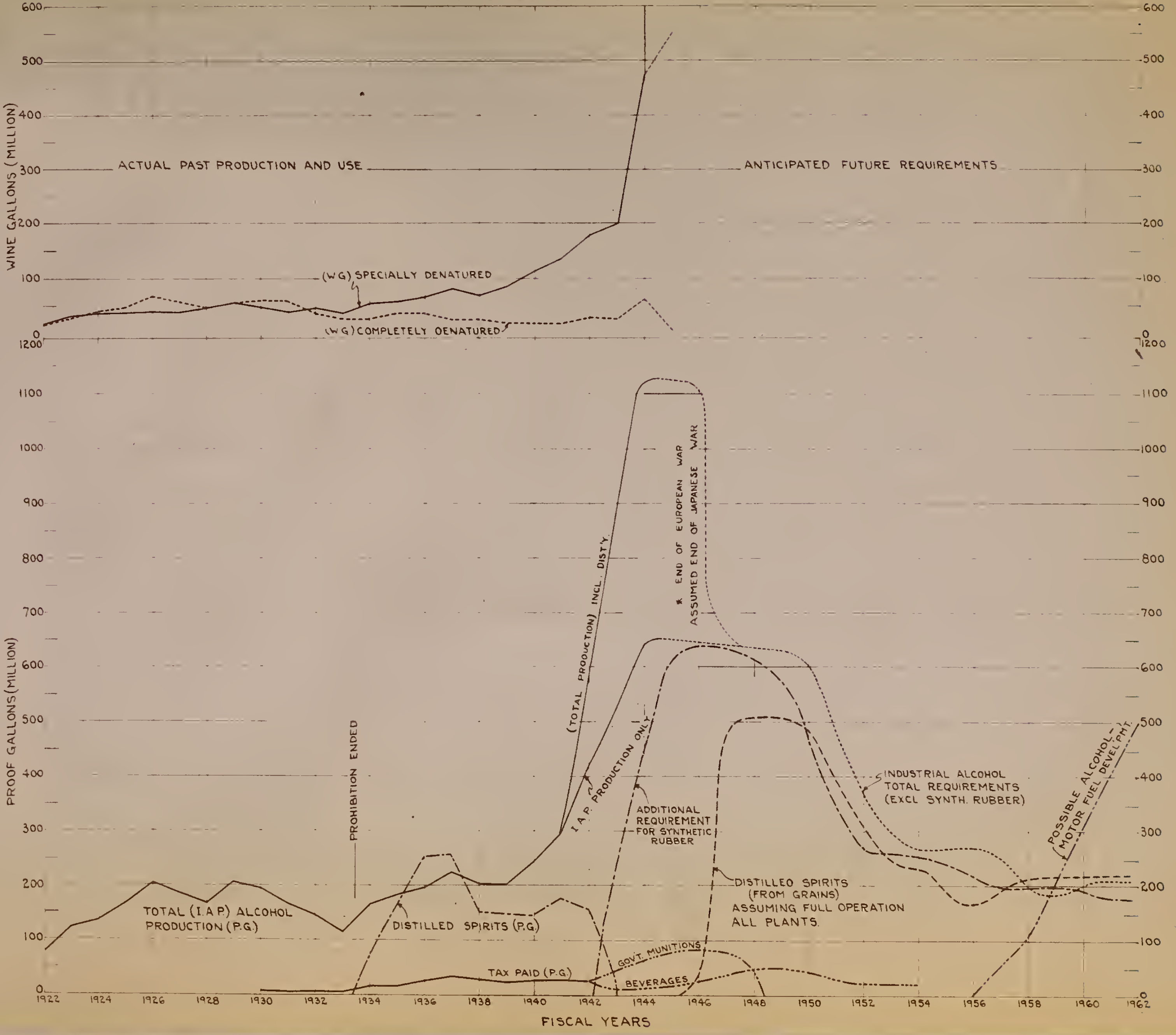
[a] Hearings, S. Res. 224. (Gillette Committee) Part II, p. 483. Later amended, Part VIII, p. 2196.

THE ALCOHOL SITUATION. FIG. 1



	Produced (percent)	Consumed (percent)
North Atlantic States (	50.6	45.2
North Central States (to Mississippi River)	11.1	23.2
Southeastern States (" " ")	19.5	20.5
Pacific Coast States	1.2	0.8
Midwestern States (west of Mississippi River)	17.5	10.2

Alcohol for Synthetic Rubber Production

The use of alcohol as a source of synthetic rubber will depend largely upon relative costs. The Buna type rubbers are made from butadiene, which can be produced from alcohol or other materials. Three parts of butadiene and one part of styrene or acrylonitrile make about five parts of finished, compounded rubber, Hence, instead of considering the problem on the more complex basis of rubber production, it is merely necessary to consider butadiene production. Butadiene can be produced from alcohol by at least three methods, and it also can be produced from butyl alcohol or butylene glycol (both derivable from farm crops by fermentation methods), as well as from petroleum. Practically 69 percent of the Government rubber program was originally designed to use petroleum as the source, since it was anticipated that butadiene probably could be produced more cheaply from petroleum than from alcohol at current raw material prices. However, the plant required for producing butadiene from petroleum is more expensive than one for producing it from alcohol, which reduces the initial raw material advantage of low-cost petroleum. Since development of the petroleum-butadiene process met unexpected difficulties, alcohol was depended upon for carrying most of the load. The principal difficulty was in the fact that petroleum-butylene needed for butadiene, was also needed for high octane gasoline production; also construction of plants operating on petroleum was delayed, and certain operation difficulties had to be overcome. In the emergency, alcohol-butadiene plants reached a production rate of 140 percent of rated capacity in 1943 and were expected to reach 150 percent in 1944, according to press reports.

Butadiene occurs as a normal constituent of the waste refinery gases obtained in the cracking of crude petroleum for gasoline, the percentage varying with the processing method and charging stock used. It can be produced in larger amounts by proper adjustment of processing factors. Current prices of petroleum butadiene are stated to be around 8 cents per pound. If petroleum prices rise through approaching scarcity or other cause, and alcohol prices decrease, alcohol may then achieve a more economic position as a butadiene source. The possibilities are shown in the following discussion.

Bradley Dewey, Rubber Director, estimated raw rubber basic values in terms of 12 to 15 cents per pound.[a] Buna S now can be produced at 14 cents per pound excluding plant depreciation but including reasonable management fees.

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[a] Nat. Pet. News, January 15, 1944, pp. 25-27.

Costs of labor, chemicals, maintenance (excluding depreciation), supervision, utilities, management (1/2 cent), and research (1/4 cent), may total 4.5 cents per pound at capacity operation. With butadiene and styrene each bringing 8 cents per pound, f.o.b. copolymer plant, the cost of producing Buna S should be 12 cents per pound, plus depreciation. A possible future reduction of 1 cent per pound is foreseen.

Since butadiene constitutes three-fourths of the mixture converted to Buna S rubber, the cost of the butadiene for one pound of Buna S is three-fourths of 8 cents, or 6 cents. The 2.2 pounds of butadiene that can be made from a gallon of alcohol will cost the value of the alcohol plus 2 cents per pound for processing charges. Alcohol at 12 cents a gallon (if obtainable at that price) would therefore entail a 7.5-cent butadiene cost (less possible byproduct credits from now-wasted oils and gases). Alcohol at 15 cents per gallon would represent a butadiene cost of 8.8 cents. In the case of butadiene from petroleum, butylenes available at a wholesale gasoline price of 5 cents a gallon should yield butadiene at a cost of 7 cents per pound, with possibly 6 cents and not over 8 cents as extremes, excluding depreciation. Styrene price may stay at 8 cents. Therefore, post-war Buna S, excluding depreciation, will cost about 12 cents a pound, as a minimum, or 14 cents as a more conservative estimate.

Plant construction costs for the above constituents, per ton of rubber per year, are approximately $79.00 for styrene, $336.00 for butadiene, and $151.00 for copolymer plant units for the lower-cost, larger plants of the rubber program. (Post-war plant construction costs would be perhaps 60 percent of these figures.) If this investment is charged off in 15 years, a depreciation charge of 1.05 cents per pound of Buna S is indicated. From the existing situation, it is obvious that a post-war price for crude rubber of 16 cents or more per pound may meet prompt competition from synthetics.

Translating the butadiene costs to grain, on the basis of available information concerning alternate routes through (fermentation) 2,3-butylene glycol or through alcohol as derived by different methods, the following data (table 13) can be derived: (Table on page 51.)

It seems obvious from the data given in table 13 that synthetic rubber cannot be economically made from alcohol produced from grain at present, since grain values would have to be lowered to around 18 to 25 cents per bushel, unless alcohol production costs from grain can be greatly reduced. These values present no inducement to the farmer. Also, assuming that the cost of (alternately) producing 2,3-butylene glycol (instead of alcohol) is approximately equal to alcohol production costs, the slight advantage of higher butadiene yields from butylene glycol would still require the grain raw material to be purchased at around 20 to 30 cents a bushel, depending upon current values of byproducts.

Table 13.- Estimated yields of butadiene from different sources and permissible cost of agricultural raw materials

Intermediate and process	Lbs./gal. of alcohol Present	Lbs./gal. of alcohol Anticipated	Lbs./bu. of corn Equivalent
Alcohol; Process A (using synthetic alc.)	2.3	2.5	6.25
Alcohol; Process B (using synthetic alc.)	2.2	3.0	7.5
Alcohol; Process C (direct pyrolysis)	2.2	2.3	5.75
2,3-Butylene glycol (13 lb. yield/bu.)a/			6.33
2,3-Butylene glycol (14 lb. yield/bu.)			6.81

Permissible cost of raw material

Raw material; intermediate; assumed yields	Comparative raw material gross value (at 6 cents per lb. of butadiene obtainable)b/
Corn; 2,3 butylene glycol; 13 lbs. per bu. = 6.33 lbs. butadiene	38.0¢ per bushel of corn
Corn; 2,3 butylene glycol; 14 lbs. per bu. = 6.81 lbs. butadiene	40.8¢ per bushel of corn
Corn; alcohol; 2.5 gals. per bu. = 6.25 lbs. butadiene (Process A)	37.5¢ per bushel of corn
Corn; alcohol; 2.5 gals. per bu. = 5.75 lbs. butadiene (Process C)	34.5¢ per bushel of corn
Blackstrap molasses; alcohol; 0.35 gal. per gal. = 0.87 lb. butadiene	5.2¢ per gallon of molasses
Blackstrap molasses, (Process A) after deducting alcohol processing cost, same basis	3.6¢ per gallon of molasses

a/ Based on 95 percent recovery efficiency and 85.4 percent conversion efficiency.

b/ Costs of making the alcohol must be deducted from these gross values.

In comparison, synthetic alcohol is understood to be producible in normal times at 12 cents or less per gallon, and, similarly, alcohol produced from sulfite liquor, or from waste wood or cellulosic agricultural wastes, may be producible eventually at 12 to 19 cents per gallon. Also, molasses was obtainable before the war at 3 to 5 cents per gallon, equivalent to 14- to 19-cent alcohol, and such prices may recur. Hence, this aspect of the alcohol market situation does not seemingly present much opportunity for economic post-war use of agricultural products, unless offsetting factors materialize.

Alcohol for Use in Motor Fuel

The idea of utilizing farm surpluses as a source of fuel has received much attention in this country within the past decade, stimulated by similar trials abroad. The employment of a motor fuel obtained from annually renewable agricultural materials would utilize the interaction of sunshine, air, water, and soil, and conserve irreplaceable naturally occurring national wealth; this advantage may outweigh mere nominal cost advantage. At the same time, such use of agricultural products can serve as a means of controlling and reducing surpluses and utilizing culls and low-grade materials, to the benefit of agriculture in general. Such use will, however, involve far-reaching economic changes, the implications and possibilities of which are now being studied, particularly by the U. S. Department of Agriculture. A program for determining and providing sources of liquid fuels for future needs has been initiated recently by Congress.

War consumption of petroleum has materially reduced below-ground reserves. How long our supply will last is not known, but certainly the annual production will decrease long before the reserves are used up. With depletion of fields, recovery costs will increase. While some new discovery of oil is to be anticipated, to a great extent, any such new supply may cost more to recover, since wells are likely to reach increasing depths, and oil deposits may be smaller than present fields. As depletion has increasing effect, rates of production will decrease. Thus, while we now have known reserves equal to about 15 years' total consumption at present rates, in actuality reserves will be available for a much longer period but for part of the consumption only. Supplementary fuels will have to be brought into use eventually unless other forms of motor power are substituted.

Chief replacements now in sight are (a) imported petroleum, (b) natural gas, (c) processed shale oil, (d) hydrogenated products from coal, and (e) alcohol or other chemical compounds produced from carbohydrates. Natural gas, while perhaps satisfactory as a fuel for stationary engines, becomes more expensive or impractical for use in mobile engines, and also represents use of irreplaceable reserves, as in fact do coal and shale oil. In the matter of relative cost, while none of the chemical products named can be made at present price levels for petroleum, alcohol can probably be made and used more cheaply than hydrogenated products of coal, with shale oil a close competitor.

For use as a blended fuel, the production cost of alcohol would have to be considerably reduced before it could compete on an economic basis with gasoline, at present prices. However, gasoline prices may increase eventually. A certain advantage accrues from the use of alcohol to raise the octane rating or antiknock value of lower grades of gasoline, and this factor may be of future importance. Since alcohol for motor fuel use possibly need not be refined (except for elimination of water) to the degree required for other purposes, considerable latitude exists as to raw materials and production methods used. Particularly, culls and partly spoiled agricultural products might be used if economically feasible. Recent experiments at the Northern Regional Research Laboratory, Peoria, Illinois, for example, have shown that rain-or frost-damaged wheat can be used for alcohol processing with little reduction of alcohol yields. Rust-damaged grain may give slightly lower yields.

Under the normal agricultural system, occasional large crops produce an unsold surplus, which disturbs the price structure. If the crop is perishable, the result is a loss to the farmer, either directly on the unsold amount or indirectly through the depressed market price. If the crop is nonperishable the hold-over surplus, if large, may affect the market in subsequent years. Also, in average as well as in bumper-crop years, accumulations of culls of certain crops occur at sorting or shipping points, and these, as well as the crop surpluses, need a market outlet or some economic method of utilization. But such outlet or utilization should not be of a nature to disturb, unduly, existing industry. Because of the large potential amounts involved, the motor fuel outlet, by a fortuitous circumstance, seems to be the one possible industrial use now known that in normal times might be able to absorb these materials, if prices were properly adjusted. The whole problem is as much economic as technical.

Some idea of the magnitude of the fuel alcohol problem is given by the following estimate: Assuming that 15 percent of any carbohydrate food crop normally represents available culls, surplus, and waste, and that it is possible to collect and successfully process all this material, one may estimate the total alcohol obtainable from all the grain, fruit, and other carbohydrate crop surpluses and wastes (22 crops in 1936, as representing an approximately normal year) as about 1,650,000,000 gallons. Gasoline consumption in 1941 was over 26.7 billion gallons. Therefore, the use of this vast amount of raw material to produce alcohol would represent only about 6.2 percent of the volume of gasoline used throughout the country as motor fuel for non-war purposes. On the further assumption that an alcohol plant of economic size produces 20,000 gallons per day or 6 million gallons per 300-day year, about 275 of such alcohol plants would be required to produce the above quantity; 445 plants would be required for a national 10-percent blend with gasoline, for which 2,670,000,000 gallons of alcohol would be required. Since it is doubtful if the total production capacity of all existing industrial alcohol and distilled spirits plants of fermentation type would exceed 600 million gallons annually, the existing industrial alcohol and beverage industries would have to be quadrupled to make sufficient alcohol for a national 10-percent alcohol-90-percent gasoline blend, exclusive of other requirements. If corn alone were used as a raw material, a billion bushels, or over one-third of a normal crop, would be required to make the necessary alcohol. If each alcohol plant costs $1,500,000 to erect, a required investment of more than a billion dollars can be visualized when costs of the necessary fuel blending, distribution, and control organization are included.

Alcohol Motor Fuel Abroad

Previous to the war, alcohol was used as a constituent of automobile fuels in Germany, France, Italy, Hungary, Sweden, Czechoslovakia, Cuba, and the Philippine Islands, and to a small extent in Australia, China, Great Britain (United Kingdom), and certain other foreign countries. All these countries were largely or entirely dependent upon imports for supplies of petroleum or petroleum products. Australia, Argentina, and other countries at the same time were confronted with large grain surpluses. In Germany, Italy, France, and other European countries that possessed comparatively small petroleum resources, the problem of replacement or substitute fuel was involved in questions of national defense and national self-sufficiency, and, consequently, efforts were made to find suitable sources of fuel. In France, alcohol production was controlled by the Government, and the industry constituted a defense measure. Alcohol surpluses only, were used for motor fuel. A somewhat similar situation existed in Italy, so that use of alcohol in motor fuel in these countries was variable and really represented surplus production of sugar beets, artichokes, grapes (wine) or similar agricultural materials. In Sweden, however, it had no agricultural significance, the alcohol being produced from sulfite liquor as a byproduct of wood pulping operations.

Germany at one time used more alcohol for motor fuel than all other countries combined. The motor fuel industry was required to purchase alcohol in proportion to the quantity of other motor fuel handled; the proportion at first was only 2-1/2 percent of imports or sales but was progressively raised until on October 1, 1932, it reached 10 percent; it remained there for several years and then decreased. Motor fuel in Germany in more recent years was a complex and varying mixture of compounds produced largely by synthetic means from many source materials such as coal, wood, and oil. The use of alcohol in various motor fuel mixtures was reported to be technically satisfactory in Germany as far as car operation was concerned. Some loss of power was reported in small, low-compression motors, but favorable results were obtained in higher-compression motors. The chief technical advantage in its use was its "antiknock" effect (octane rating). But, according to consular reports, alcohol motor fuel was found to be distinctly uneconomical. While benefiting only a relatively restricted part of the population, notably the potato growers and distilleries situated chiefly in eastern Germany, it had adverse effects of increasing the already high cost of motor fuel and thus retarding the country's motorization while lessening potential government income.

The Cuban government now has an active alcohol motor fuel program and alcohol plants have been built and molasses supplies reserved for this purpose. Other semi-tropical countries have experimented with the idea. In the tropics the fuel mixtures usually contain higher percentages of alcohol than elsewhere.

Post-War Aspects of Alcohol Motor Fuel

While the capacity of the industrial alcohol industry apparently will be more than ample for supplying later post-war industrial alcohol requirements, any earlier use of alcohol for fuel would intensify the probable supply shortages. For successful use of alcohol in motor fuel, as blended with ordinary gasoline, at least 5 percent and possibly 10 percent should be employed, to derive essential benefits from the admixture. Since the pre-war automotive fuel requirements of the country exceeded 25 billion gallons annually, the need of alcohol in vast amounts can be visualized; possibly more than 3 billion gallons would be required for a 10-percent blend with all motor fuel consumed. Production of alcohol in such quantities lies far beyond the scope of the alcohol industry as now constituted.

In the immediate post-war period there are likely to be amply supplies of premium type gasoline fuel available. Eventually, a shortage of petroleum may lead to the development and supplemental use of synthetic fuels, particularly for use in small, high-powered engines. In this event, alcohol may find increasing use. However, the use of alcohol in blended motor fuel is more likely to be brought about, or given impetus, by the gradual reduction of alcohol markets as the war-engendered alcohol requirements subside, particularly if this slackening market is paralleled by an increasing surplus of grain and a reduction of general industrial activity. Such a combination of conditions, especially if coupled with a petroleum shortage, is likely to stimulate great political pressure for the use of blended alcohol motor fuel as a solution of the situation, as was manifest in 1931-2.

Considered from agricultural aspects, a means of utilizing crop surpluses and culls is presented. Crop production and markets must be studied to determine feasibility of a program. However, the setting up of a sort of scavenger industry to make indeterminate and varying amounts of alcohol for sporadic manufacture of blended fuels of nonstandard quality is not likely to yield results satisfactory to the agricultural program or to the motoring public. Any large use of American crops to feed other nations will probably preclude the possibility of developing a sound or extensive alcohol motor fuel program for many years.a/

Post-war trends probably will tend toward the use of automobile engines consuming less fuel per mile. Lower fuel consumption can be achieved by use of higher compression ratios. An eventual octane rating of 80-84 for ordinary automobile gasoline, with 88-92 octane for special fuelsa/, can be visualized. However, too much dependence should not be placed on radical developments in this direction. The use of high compression may entail the use of a fuel of relatively high octane value. But the production of fuels of high octane

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a/ D. P. Barnard, Res. Div., Standard Oil Company of Indiana, SAE Proceedings, January 10, 1944.

values involves increased crude petroleum consumption per unit of gasoline produced. Also, high compression calls for heavier engine construction, which involves extra weight and cost. It is obvious that there are economic limits. The use of alcohol or similar substances to increase antiknock values may offset extra crude oil consumption to some extent, but the problems of avoiding extra weight and increased engine cost still remain to be solved.

Alcohol can be used as a straight fuel without admixture with gasoline, but present costs are prohibitive. However, the use of straight alcohol fuel in injection type engines, recently initiated, may have unpredictable effect on the situation. Exhaustive research is now being conducted on engine design, and the whole situation is in a state of flux. Recent developments in turbine type engines, jet and rocket propulsion are noteworthy.

Another factor in the use of petroleum and its substitution by synthetic fuels should be considered. Petroleum now constitutes the major source of lubricating oil, the quality of which is of even more importance than the quality of motor fuel. At present, this oil is one of the products of the process whereby petroleum is split into gasoline, heating oil, lubricating oil, waxes, and other important commercial commodities. Gasoline and heating oil can be substituted by shale oil, hydrogenation products of coal and wood, alcohol, etc., but the ability of their manufacturing processes to yield suitable lubricating oils is not wholly explored. Hence, in the absence of newly discovered suitable lubricating-oil substitutes, the processing of petroleum may have to be aimed increasingly at lubricating oil production at the expense of other products, in future years, if a shortage develops. However, as long as any significant production of petroleum is attainable, the lubricating oil supply should not be endangered.

Although petroleum reserves in the United States are being reduced, this does not necessarily imply an immediate shortage of petroleum products. Importation costs for petroleum are understood to range from 7 to 12 cents per barrel (42 gallons) of crude, for oil originating in the Caribbean area. Such costs would entail gasoline cost advances of 1 cent or less per gallon. There is much oil production development in the Caribbean, South American, Mexican, and Canadian areas, and these areas have not been as extensively explored as the United States fields; so further oil discoveries may be anticipated.

Other Possible Future Motor Fuels

Future motor fuels may also be derived from polymerization of gases (such as waste gas from petroleum cracking processes, natural gas, water, (blau) gas, or similar low-cost sources); wood, or other solid fuels, such as carbon, may be used. For operating the engines on motor vehicles, solid fuel may be changed to a burnable gas by means of a gas-generating system attached to the vehicle. It might also be possible to generate power by explosions of minute charges of a solid fuel within a specially designed engine. Because of war conditions abroad and the consequent scarcity of gasoline, there has been much development of such motor propulsion methods, particularly in England and Germany with gas-generator types of engines. It may be expected that under post-war conditions the automotive industry will take any steps necessary to keep abreast of changes in the fuel situation, and that any change will be one of gradual evolution.

Blending Agents for Alcohol-Gasoline Fuels

Gasolines do not form a wholly stable mixture with ordinary 95-percent alcohol; and they may separate into two layers when the temperature is lowered, or when water is added even in small amounts. However, when 99.5-percent alcohol is used, the mixture becomes relatively more permanent. To avoid separation "blending agents," such as butyl alcohol, acetone, and benzol, may be added to commercial alcohol-gasoline blends to increase the water tolerance of the mixtures. These blending agents frequently have better fuel values then ethyl alcohol, and some of them, such as butyl, isopropyl and amyl alcohols, acetone, and ether can be produced from farm crops. However, under reasonable precautions, or in certain climates, use of blending agents may not be necessary. In this connection, problems of illegal recovery of alcohol for illicit beverage use are certain to arise.

Behavior of Ethyl Alcohol in an Internal Combustion Engine

In comparison with about 18,900 B.t.u.[a] for the usual motor-grade gasoline, the net heat of combustion of anhydrous alcohol is only about 11,520 B.t.u. per pound. However, the actual fuel-air mixture, as drawn into the engine, will run about the same in B.t.u. value (100 B.t.u. per cu. ft.) for both alcohol and gasoline. While alcohol has only approximately 60 percent of the fuel or power value of gasoline, it can be employed at higher compression ratios, resulting in a net yield of power greater than that indicated by its heat value. Alcohol burns cleanly, without formation of carbon. It has a higher viscosity, but a lower flame temperature and a different flame-propagation rate, as well as a different boiling characteristic than gasoline. Thus, considerably different conditions are set up within the engine when alcohol or alcohol blends are used. Alcohol when added to gasoline, increases the "octane rating" to a variable degree, depending on the gasoline. To secure maximum effect of alcohol, however, compression ratios should be increased and carburetor-jet size increased. In the modern car using higher compression ratios, blends of alcohol up to 10 percent would probably function about as efficiently as gasoline without much noticeable variation in performance of the motor. Blends containing larger percentages of alcohol might show decreased mileage per gallon of fuel used. The presence of alcohol in the fuel would tend to remove deposited water from fuel systems, thereby preventing freezing of fuel lines in cold weather. Alcohol has a tendency to clean the gum from fuel lines, and to burn carbon from dirty engines; it may thus improve the efficiency of an old car by such cleaning action. Because of the presumable interchangeability of 10-percent blends and straight gasoline in modern cars, it might not be necessary to effect blending on a national scale, as previously implied, provided all blends were uniform. Alcohol has been shown to be non-corrosive, per se, in fuel use.

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[a] For fuel in liquid state (water of combustion considered in vapor stage): The Internal Combustion Engine, Taylor, 1938, 1st Ed., p. 159.

Alcohol From Waste Products of the Farm

The suggestion has been made that the manufacture of industrial or denatured alcohol on the farm would provide a means for the farmer to dispose advantageously of certain crop surpluses and wastes, the derived alcohol being utilized as a motor fuel, etc., on the farm. A careful analysis of all the factors entering into the question leads to the conclusion that there is little likelihood that home distilleries of present known design can be operated with satisfaction or profit. The main reasons for such a conclusion are: (a) A fermentation process must be carefully controlled if a satisfactory yield and quality is to be obtained, and the average farmer does not have sufficient technical training or equipment to achieve this effectively; (b) the cost of installation of the small manufacturing unit is relatively high; (c) the labor cost is actually excessive and the output small; (d) the supply of raw material is likely to be both variable and intermittent; (e) storage of available raw material is difficult; and (f) the unit cost of production would be so high that the farmer ordinarily could buy industrial alcohol cheaper than he could make it. Furthermore, existing laws must be modified or repealed before such operations would have a legal status. Problems of illegal diversion of alcohol would multiply. The value of the feed residues from such process has been perhaps overstressed, since these are not likely to exceed the value of the original materials, when costs of handling, etc. are considered.

It has also been proposed that fermentable farm culls be utilized in central distilleries for the production of alcohol. Such a plan has greater merit, although its economy is debatable, principally for the reason that cull materials usually have a relatively low content of fermentable matter. Transportation charges of the raw material practically might be prohibitive if it is necessary to bring such low-grade material from a distance to a central point. Continued supplies of certain materials might be difficult to obtain to assure year-round operation. Rather large-scale operation would be necessary to permit carrying adequate trained personnel. Extensive research and study on this type of operation would have to be made, and present conventional processes might have to be modified.[a]

The present commercial production of ethyl alcohol from molasses, grain, or by synthesis, sets a competitive price standard which must be met. Crop surpluses, culls, and wastes usually constitute poor material that is relatively unsalable in standard market grades. Such material may be relatively low in carbohydrate content, and may contain dirt, excess moisture, fungi or molds, etc. The relative cost of the alcohol produced from such sources probably will be high, or the quality poor, at least in regard to odor and taste. Many of the possible cull materials are perishable and

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[a] The idea of a mobile alcohol plant has recently been proposed.

will be lost unless processed with reasonable speed. Moreover, surpluses vary in quantity from year to year. A program of alcohol production from these materials involves the maintenance of alcohol plants and personnel at central points, and such plants must have enough available raw materials to assure year-round operation for every year. It is not economical to build expensive alcohol plants and then depend on sporadic operation as cull or surplus materials become available. For plants with relatively low outputs of 2,000-2,500 gallons per day, it would be difficult to maintain adequate technical supervision without incurring relatively high per-gallon costs.

APPENDIX

Table 1

Table 2

Table 3

Table 4

Table 5

Table 7

Table 9

Table 10

Table 1.- Industrial alcohol production and use

Fiscal year	Total alcohol production. proof gals.	Amount withdrawn as tax-paid. proof gals.	% of total	Used for denaturing.[b/] proof gals.	Denatured alcohol produced	
					Specially denatured wine gals.	Completely denatured wine gals.
					(Includes Porto Rico)	
1920	98,436,170	22,639,356	23.0	45,640,948	15,307,947	13,528,402
1921	85,068,776	26,275,969	30.9	39,343,251	9,996,229	12,392,595
1922	79,906,101	16,391,490	20.5	61,177,444	17,152,224	16,193,523
1923	122,402,849	10,763,613	8.8	109,519,332	30,436,913	27,128,229
1924	135,897,725	9,382,302	6.9	125,378,523	33,085,292	34,602,003
1925	166,165,518	8,547,518	5.2	152,254,039	34,824,303	46,983,969
1926	202,271,670	8,801,399	4.35	195,480,934	39,494,443	65,881,442
1927	184,323,016	8,253,513	4.39	173,570,104	39,354,933	56,093,748
1928	169,149,904	8,675,717	5.24	161,362,455	45,451,424	46,966,601
1929	200,616,750	8,892,513	4.45	186,045,935	54,623,207	53,296,717
1930	193,823,717	8,251,274	4.27	185,000,827	47,713,468	59,063,510
1931	168,109,617	7,398,867	4.45	152,606,700	37,414,521	50,000,627
1932	146,950,912	6,154,449	4.2	136,388,865	44,541,336	35,002,096
1933	115,609,754	5,020,625	4.4	107,657,981	35,800,271	27,275,071
1934	165,103,582	16,154,614	10.3	139,681,129	55,067,092	27,174,311
1935	180,645,920	16,990,972	9.3	165,233,606	58,284,395	38,746,679
1936	196,126,236	24,052,532	12.0	174,357,295	64,955,485	36,522,358
1937	223,181,228	32,289,650	15.0	181,034,322	80,084,281	22,118,378
1938	201,033,858	28,976,609	14.7	165,848,246	69,009,024	25,598,717
1939	201,017,546	22,150,969	11.0	177,336,688	83,561,077	17,179,433
1940	243,727,756	24,344,306	9.7	225,160,792	111,409,797	15,352,033
1941	(298,845,417 (IAP), (20,200,583 (Disty)[a/]	27,866,523	8.8	276,766,361	135,834,261	17,676,172
1942	(424,408,401 (IAP), (82,079,771 (Disty)	(24,932,340 (IAP) (26,123,554 (Disty)	10.0	374,760,259	179,217,153	28,628,181
1943	(732,350,228 (IAP and Disty)	40,313,222 (IAP and Disty)	5.5	408,303,779	198,524,631	24,369,788
1944	987,957,702 (IAP+D)	26,186,608 (IAP and Disty)	2.64	973,439,556	471,781,825	52,331,761

a/ Used for beverage wholly in 1941 and partly in 1942. Net amount, as industrial alcohol was 517,500,002 in 1942.

b/ Includes rum used for denaturing prior to 1943. Includes amounts used for denaturing in Porto Rico since 1929. Since 1943, imported alcohol is included. Prior to 1942 the amounts were "withdrawn" for denaturation, since 1942 the amounts were "used" for denaturation.

Table 2.- Production of distilled spirits[1]

Year ending June 30	Total production (proof gals.)	Whiskey production (proof gals.)	Total stocks of distilled spirits on hand, June 30; (proof gals.) (original gauge)	Total number of[2] plants operating	Daily capacity represented (proof gals.)
1933	End of prohibition era		20,716,695	31	60,000
1934	76,506,388	62,352,666	63,065,017	136	750,000
1935	169,126,472	149,112,923	160,755,394	228	1,094,114
1936	253,867,925	223,659,539	310,803,839	269	1,301,347
1937	258,956,886	223,457,850	462,607,980	273	1,477,365
1938	150,155,924	102,895,872	497,527,755	256	1,457,390
1939	145,326,176	93,003,917	522,058,134	241	No data
1940	143,455,192	98,993,303	525,394,924	221	No data
1941	175,208,746	121,851,983	551,424,175	232	No data
1942	157,981,798	120,257,424	538,910,306	-	-
1943	39,916,974[a]	19,529,698	439,508,771	-	-
1944	23,804,845[a]	None	361,559,629	-	-
1945	70,637,178	41,562,303	(10 months operation)		

[1] Includes production of fruit distilleries, rum plants, and gin plants.

[2] Number of grain distilleries were:

Fiscal year 1933-- 7 1937--127 1941-- 97
1934--46 1938--108 1942--130
1935--82 1939--103 1943--131 (grain alcohol and rum distilleries)
1936--113 1940-- 94

[a] Rum, gin, and brandy only.

Year ending June 30	Grain equivalent of distilled spirits produced (56-pound bushels)			
	Corn	Rye	Malt	Misc'l or wheat
1933	End of prohibition era		-	-
1934	7,835,666	4,471,613	2,127,374	47,398 W
1935	18,222,666	10,170,985	4,557,621	55,347 M
1936	29,306,002	12,562,587	6,221,831	66,356 M
1937	32,698,074	11,551,036	6,394,013	59,437 M
1938	16,448,145	5,958,563	3,210,582	41,831 M
1939	15,289,600	5,452,554	2,719,270	58,458 W
1940	16,468,000	5,534,102	3,028,870	31,858 W
1941	20,279,223	6,463,553	3,811,465	45,010 W
1942	No breakdown available		-	-
1943	No use of grain		-	-
1944	No use of grain		-	-

Table 3.- Uses of specially denatured alcohol [1] [2]

General Field of Application	Fiscal year 1936: Total specially denatured alcohol used (new and recovered)	Fiscal year 1942: Total specially denatured alcohol used (new and recovered)	Fiscal year 1942: New specially denatured alcohol used
	Millions of wine gallons		
Lacquers, varnishes and enamels	9.3	9.1	7.7
Plastics	5.4	6.1	4.8
Film, explosives, adhesives	2.4	89.1[3]	28.0[4]
Solvents and thinners	10.6	24.5	24.5
Processing industrial food and drug products	27.1	72.2	9.4
Toilet preparations	3.3	5.6	5.6
Pharmaceuticals (external)	3.4	3.7	3.6
Cleaning, preserving, flavoring	1.9	2.8	2.8
Converted in chemical manufacturing:			
Acetaldehyde	16.6	52.4	34.4
Vinegar and ethyl acetate	12.7	19.1	18.1
Other	15.9	32.6	22.2
Miscellaneous	0.5	8.5	8.1
Total	109.1	325.7	169.2

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[1] Table prepared by Alcohol Tax Unit

[2] Completely denatured alcohol is mostly used for antifreeze, varnish and lacquer thinner, canned heat, and crude solvent (where the distinctive odor does not impair the finished product).

[3] Explosives alone, 85.4.

[4] Explosives alone, 26.8.

Table 4.- The industrial alcohol industry[1]

(Estimated plant production capacities 350-day operation basis, wine gals. 190° proof per day)

	Industrial alcohol plant number
(a) Synthetic alcohol plants (4 plants)	
Carbide and Carbon Chemicals Co., Whiting, Ind.	218
Standard Oil Company of Louisiana, Baton Rouge, La.	316
Carbide and Carbon Chemicals Co., Texas City, Tex.	241
Carbide and Carbon Chemicals Co., S. Charleston, W. Va.	180
Total production, Category (a) 219,000	
(b) Chemical byproduct plants (3 plants)	
American Cyanamid Co., Boundbrook, New Jersey	247
Hercules Powder Co., Hopewell, Virginia	238
E. I. du Pont de Nemours, Belle, W. Va.	233
Total production, Category (b) 8,000	

Annual total, non-fermentation plants - 79,450,000 gallons

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[1] Plants classified on basis of normal operation. Several borderline plants are included. Deviations from normal procedures are shown, where possible. List of plants as of March 1945, from Alcohol Tax Unit. Daily production estimates are based on War Production Board data, with estimates from other sources when data were not available. A 350-day year is assumed, and production rates represent probable maximums obtainable in long-period operations. In the case of distilleries also listed as industrial alcohol plants (section h) full production is allocated to industrial alcohol, unless otherwise indicated.

Table 4.- The industrial alcohol industry--Contd.

(c) Molasses fermentation plants (18 plants) (exclusive of butyl plants and wineries)	Industrial alcohol plant number
American Distillery Co., (Calif. Reg. Disty. #4) Sausolito (formerly IAP No.)	
Commercial Solvents Corp., Agnew, Calif.	25
Lac Chemicals, Inc., Culver City, Calif.	224
U. S. Industrial Chemicals, Anaheim, Calif.	112
Chartres Alcohol Co., New Orleans, La.	225
Commercial Solvents Corp., Harvey, La.	31
Commercial Solvents Corp., Westwego, La.	128
Gulf Distilling Company, Gretna, La.	170
Publicker Commercial Alcohol Co., Westwego, La.	239
New England Alcohol Co., Everett, Mass.	201
E. I. de Pont de Nemours Corp., Deepwater Point, N. J.	168
U. S. Industrial Chemicals, Inc., Newark, N. J.	158
Publicker Commercial Alcohol Co., Philadelphia, Pa.	29 (part)
Publicker Commercial Alcohol Co., Philadelphia, Pa.	160 (part)
Pennsylvania Alcohol Co., Philadelphia, Pa.	140
Red Star Yeast and Products Co., Milwaukee, Wis. (Beet molasses)	46
(Part production from butyl plants	
U. S. I. #2 - New Orleans, La. (part)	
U. S. I. #1 - Baltimore, Md. (part)	

Total production, Category (c) 567,800

Annual equivalent - 198,730,000 gallons

(d) Wineries, (using molasses) (8 plants) (Calif.)

Bisceglia Bros. Wine Co., Wahtoke	329
Franzia Bros. Winery, Manteca	313
Petri Wine Co., Escalon	333
San Gabriel Vineyard Co., San Gabriel	340
San Martin Vineyards Co., San Martin	331
Sunnyside Winery, Fresno	298
Roma Wine Co., (now inactive) (Cal. Reg. Disty. #11)	
E & J Gallo (now inactive) Modesto	(312)

Total production, Category (d) 28,400

(e) Territorial (molasses) plants (3 plants)

Distileria Seralles, Inc., Ponce, Puerto Rico	222
Puerto Rico Distilling Co., Arecito, Puerto Rico	179
California Packing Co., Honolulu, Hawaii	77

Total production, Category (e) 30,000

Total annual capacity from molasses (c, d, e,) -- 219,170,000 gallons

Table 4.- The industrial alcohol industry--Contd.

(f) Grain distilling plants (12 plants) Contd.	Industrial alcohol plant number
Bisceglia Distilling Co., Peoria, Ill. (Ill. 9)	311
U. S. Dept. of Agriculture, Peoria, Ill.	267
Clinton Products Co., Clinton, Iowa	280
Grain Processing Corp., Muscatine, Ia.	345
Midwest Solvents Co., Atchison, Kansas	217
Boeckler Associates, Trenton, Mich.	273
National Distillers Products Co., Kansas City, Mo.	348
Farm Crops Processing Corp., Omaha, Neb.	349
Genesee Brewing Co., Rochester, N. Y.	256
U. S. Industrial Chemicals Inc., Yonkers, N. Y.	223
Publicker Commercial Alcohol Co. (Grain Div.)	(160) (part)
Dakota Distillery Co., Huron, S. Dak.	356
Yankton Industrial Alcohol Co., Yankton, S. Dak.	337

Total production, Category (f) 400,500

Annual producing capacity from grain (f) 140,175,000 gallons

(g) Miscellaneous plants (5 plants)	
Bonneville Distilleries Inc., (Idaho Reg. Disty. #1) Idaho Falls, Idaho (now operating on potatoes)	346
Consolidated Products Co., Nixa, Mo. (not operating. Uses grain)	336
Commercial Solvents Corp., Terre Haute, Ind. (Understood to operate normally as a redistillation plant only--non-producing)	200
Puget Sound Pulp & Timber Co., Bellingham, Wash. (Sulfite liquor)	357
The Sotol Co., Del Rio, Tex. (operated on sotol -- 1944. Now inactive)	352

Total production, Category (g) 9,200

Annual -- 3,220,000 gallons

Total indicated annual capacity, sections a to g inclusive, (which probably represent the portion of production normally attributable to the industrial alcohol industry proper),-- 442,015,000 gallons. (53 plants).

(h) Plants normally operating as distilleries (grain operations) (15 IAP plants) (in 17 distilleries) (Duplicated production)	
Hiram Walker & Sons (Ill. #3) Peoria, Ill.	215
Century Distilling Co. (Ill. #4) Peoria, Ill.	202
The Old Quaker Co., (Ind. #2) (formerly Ind. #7) Lawrenceburg, Ind.	226
Commercial Solvents Corp. (Ind. #3) Terre Haute	59

Table 4.- The industrial alcohol industry--contd.

(h) Plants normally operating as distilleries (grain operations) (15 IAP plants) (in 17 distilleries)	Industrial alcohol plant number
National Distillers Products Co.,	
(Ky. #3) Louisville, Ky.	301
(Ky. #4) Bardstown, Ky.	289
(Ky. #14) Forks of Elkhorn, Ky.	330
(Ky. #19) Louisville, Ky.	288
(Ky. #25) Glenns Creek, Ky.	347
(Ky. #47) Gethsemane, Ky.	309
(Ky. #106) Louisville, Ky.	354
Monticello Distilling Co., (Md. #6)	
Cedarhurst, Md.	251
National Distillers Products Corp.	
(Ohio #1) Cincinnati, Ohio	213
Continental Distilling Corp., (Pa. #1) (?)	
Philadelphia, Pa.	(160)x/ y/ (part)
A. Overholt & Co., (Pa. #3) Broadford, Pa.	281
A. Overholt & Co., (Pa. #5) Large, Pa.	283
Continental Distilling Co., (Publicker)	
(Pa. #14) Philadelphia, Pa.	(29) (Part) y/

Total production, Category (h) 302,900

Annual equivalent - 106,015,000 gallons

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x/ Capacity assumed to be additional to listings under 160 (butyl, molasses, and grain).

y/ This plant originally utilized molasses, but recently was equipped for grain, according to present understanding. The production capacity of these plants is relatively so large that general totals in the table are significantly affected by any distribution of such production to the various groups. Such distribution has been made on the basis of actual 1944 operations, as far as these can be determined.

Table 4.- The industrial alcohol industry--Contd.

(i) Plants normally producing butyl alcohol, with some ethyl production (5 plants) z/ Operating on grain or molasses	Industrial alcohol plant number
Commercial Solvents Corp., Peoria, Ill. (Normally operates wholly on butanol)	132 (G) or (M)
U. S. Industrial Alcohol Co., New Orleans, La. (Part operation on butanol)	(2) (M)
U. S. Industrial Alcohol Co., Baltimore, Md. (Part operation on butanol)	(1) (M) (WF) (part)
Publicker Commercial Alcohol Co., Philadelphia, Pa. (Butanol plant separate from other listings)	(160) (M) (GWF)
Associated Azacareara Corp., LaFayette Arroyo, Puerto Rico (Operates wholly on butanol	237 (M)

Total production, Category (i) as W.G. 190° P. per day - 288,000

Total annual nominal capacity represented by butyl operations--
80,500,000 -- 100,800,000 gallons.

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z/ Only nominal amounts of alcohol are recovered, under butanol-acetone operations. The potential ethyl alcohol production capacity shown is computed on the basis of actual butanol operations, 1944, interpolated to ethanol. The 56.8 million gallons of molasses and 6.9 million bushels of grain actually used for butanol production in 1944, alternatively might have produced about 40.2 million gallons of ethyl alcohol. Assuming that mash concentrations (conservatively) might have been doubled in such operation, an alternative production of ±80.5 million gallons of ethyl alcohol might have been conceivable, if adequate distillation and processing equipment was available. (In actuality, mash concentrations might be almost trebled, but fermentation time increases and conceivable plant difficulties or bottlenecks would affect the potential amounts. Computed on another basis, using older capacity ratings derived from the Alcohol Tax Unit, or other sources, a potential 100,800,000-gallon capacity is indicated.) However, under normal conditions, only nominal amounts of ethyl alcohol could be depended upon, because of market demands for butanol and acetone.

Table 5.- The distilled spirits industry

(All plants operate on grain unless otherwise specified.)

(Estimated plant production capacities, 350-day annual operation basis, wine gallons 190° proof, per day)

Class (A) Distilleries now operating as industrial alcohol plants for whole or part time. (See appropriate Section H, under Industrial Alcohol Plants. Table 4.)

Production capacity represented - 17 plants

Total production, Class (A)

(302,900)
Duplicated
production

Annual total - 106,015,000 gallons

Class (B) Distilleries (not operating as industrial plants) (92 plants)

Number

Ariz. #1 - Schenley Distilleries, Inc., Phoenix
Cal. #2[m] - Hedgeside Distillery Corp., Napa
Conn. #1 - United Distillers Products Corp., Hebron (Amston)
Ill. #1 - Hiram Walker & Sons, Inc., Peoria
Ill. #2 - The American Distilling Co., Pekin
Ill. #7 - Columbia American Distillers, Inc., Columbia
Ill. #8 - Belvidere Distilling Co., Belvidere
Ind. #1 - Joseph E. Seagram & Sons, Inc., Lawrenceburg
Ind. #4 - James Walsh & Co., Inc.
Ind. #5 - Merchants Distilling Corp., Terre Haute
Ind. #6 - Park & Tilford Distillers, Inc., Tell City
Ind. #8 - W. P. Squibb Distilling Co., Inc., Vincennes
Ky. #1 - Bernheim Distilling Co., Louisville
Ky. #2 - Bernheim Distilling Co., Louisville
Ky. #5 - Jas. E. Pepper & Co., Lexington
Ky. #6 - Park & Tilford Distillers, Inc., Louisville
Ky. #7 - Frankfort Distilleries, Inc., (Seagram) Louisville
Ky. #8 - Grosscurth Distillers, Lawrenceburg
Ky. #9 - Associated Kentucky Distilleries Co., Lebanon
Ky. #10 - Fleischmann Distilling Corp., Owensboro
Ky. #12 - Barton Distilling Co., Bardstown
Ky. #13 - Churchill Distilling Co., Churchill

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[m] Calif. #4 shown on IAP list, although now listed as a distillery.

Table 5.- The distilled spirits industry--contd.

Class (B) Distilleries (not operating as industrial plants)

Continued

Number

Ky. #15 - Old Lewis Hunter Distillery Co., Lair (Cynthiana)
Ky. #16 - Stitzel-Weller Distillery, Shively
Ky. #17 - Frankfort Distilleries, Inc., Louisville
Ky. #18 - Geo. T. Stagg Co., Limestone Springs
Ky. #20 - Cummins-Collins Distilleries, Athertonville
Ky. #21 - Blair Distilling Co., St. Francis
Ky. #22 - The H. E. Pogue Distillery Co., Maysville
Ky. #23 - Dowling Distillers, Inc., Burgin
Ky. #24 - Glenmore Distilleries Co., Owensboro
Ky. #27 - Ripy Bros. Distillers, Lawrenceburg
Ky. #28 - Shawhan Distillery Co., Bardstown
Ky. #30 - General Distillers Corp. of Ky., Louisville
Ky. #31 - Old Heaven Hill Springs Distillery, Bardstown
Ky. #33 - Old Poindexter Distiller, Inc., Ekron
Ky. #35 - Bonds Mill Distilling Co., Lawrenceburg
Ky. #36 - Blue Ribbon Distilleries Co., Carrollton
Ky. #37 - Jos. E. Seagram & Sons, Inc., Louisville
Ky. #39 - John P. Dant Distillery Co., Inc., Meadowlawn
Ky. #40 - Old Colonel Distillery, Midway
Ky. #41 - Loretto Distilling Co., Loretto
Ky. #42 - Fairfield Distillery, Inc., Bardstown
Ky. #45 - Kentucky River Distillery, Inc., Camp Nelson
Ky. #48 - Dant & Dant of Kentucky (Seagram) Louisville
Ky. #49 - Medley Distilling Co., Owensboro
Ky. #50 - Park & Tilford Distillers, Inc., Midway
Ky. #51 - Willow Springs Distillers, Inc., Greenbrier
Ky. #52 - Brown-Forman Distillers Corp., Frankfort
Ky. #105 - Green River Distilling Co., Stamping Ground
Ky. #111 - H. McKenna, Inc., Fairfield
Ky. #113 - Geo. T. Stagg Co., Frankfort
Ky. #145 - Country Distillers Products, Deatsville
Ky. #230 - James B. Beam Distilling Co., Clermont
Ky. #240 - Yellowstone, Inc., Louisville
Ky. #414 - Brown-Forman Distillers Corp., Louisville

Table 5.- The distilled spirits industry--contd.

Class (B) Distilleries (not operating as industrial plants)

Continued.

Number

Md. #1 - Paul Jones & Co., Inc., Baltimore
Md. #3 - Calvert Distilling Co., Baltimore (Relay)
Md. #5 - Frank L. Wight Distilling Co., Loreley
Md. #7 - James Distillery, Inc., Baltimore
Md. #8 - Park & Tilford Distillers, Inc., Owings Mills
Md. #9 - Hunter-Wilson Distilling Co., Inc. Owings Mills
Md. #10 - Harford County Distillery, Inc. Havre de Grace
Md. #11 - Monumental Distillers, Inc., Lansdowne
Md. #12 - The Sherwood Distilling Co., Westminster
Md. #13 - United Distillers of America, Ltd., Baltimore
Md. #14 - Carrollton Springs Pure Rye Distillery, Inc., Baltimore
Mass. #4 - Berke Bros. Distilleries, Inc., Readville
Mass. #8 - Consolidated Distilleries, Inc., East Taunton
Mass. #9 - Highland Distilleries, Inc., Boston
Mo. #2 - Ozark Mountain Distilling Co., Joplin
Mo. #4 - Jefferson Distilling Co., Labadie
N. Y. #1 - The Fleischmann Distilling Corp., Peekskill
Ohio #2 - Siegfried Loewenthal Co., Cleveland
Ohio #3 - Dant & Dant of Kentucky, Bedford
Ohio #6 - Cedar Valley Distillery, Inc., Wooster
Pa. #4 - Jos. S. Finch & Co., Inc., Schenley
Pa. #6 - Logansport Distilling Co., Inc., Logansport
Pa. #8 - Dillinger Distilleries, Inc., Ruffsdale
Pa. #9 - Manor Distilleries, Inc., Manor
Pa. #10 - Kinsey Distilling Corp., Linfield (Publicker)
Pa. #11 - Foust Distilling Co., Inc., Glen Rock
Pa. #12 - Frantz Distillers, Inc., Meyersdale
Pa. #15 - Park & Tilford Distillery, Inc., Brownsville
Pa. #16 - Mid-Valley Distilling Corp., Archbald
Pa. #19 - David Meade Distilling Co., Meadville
Pa. #20 - Old Clover Distilling Co., Aldovin
Vt. #1 - Lawrence Distilling Co., Burlington
Va. #1 - Virginia Distillery Corp., Dumbarton
Va. #2 - Old Dixie Distilling Co., Inc., Richmond
Va. #3 - A. Smith Bowman Distillery, Sunset Hills
Va. #4 - Belle Meade Distilling Corp., Belle Meade
Total production, Class (B) - 93 plants 533,400

Annual total 186,690,000 gals.

Table 5.- The distilled spirits industry--contd.

Estimated daily production capacity wine gals. 190°-proof

Class (C) Distilleries (20 plants)

Number

Col. #2 - Con Moore's Distillery, Arvada
Ga. #1 - Paramount Distillers Products Corp., Albany
Ky. #26 - Waterfill & Frazier Distillery Co., Anchorage
Ky. #29 - J. T. S. Brown's Son Co., Bardstown
Ky. #34 - Pebbleford Distillers, Inc., Wilder
Ky. #43 - The Willett Distilling Co., Bardstown
Ky. #44 - Old Happy Hollow Distillery, Loretto
Ky. #53 - The Old Taylor Distillery Co., Frankfort
Ky. #112 - Hoffman Distilling Co., Lawrenceburg
Ky. #169 - Dant Distillery Co., Dant
Ky. #354 - Brown-Forman Distillers Corp., Louisville
Md. #2 - National Distillers Products, Corp., Baltimore
Md. #4 - Paul Jones & Co., Inc., Baltimore
Md. #27 - National Distillers Products, Corp., Baltimore
Mo. #5 - McCormick Distilling Co., Weston
Mo. #8 - Washington Distilleries, Inc., Washington
Pa. #17 - Penndale Distilling Co., Schaefferstown
Pa. #21 - W. A. Haller Co., Inc., Elverson
Tenn. #1 - Jack Daniel Distillery, Lynchburg
Wis. #1 - W. B. Gambill Distilling Co., Crandon

Total production, Class (C) (20 plants) (41,000)

Annual -- 14,350,000 gallons

(D) Miscellaneous (7 plants)

Ky. #11 - New England Distilling Co., Covington
Mass. #2 - New England Distilleries, Inc., Clington (rum)
Mass. #5 - Felton & Son, Inc., South Boston (rum)
Mass. #6 - A. & G. J. Caldwell, Inc., Newburyport (rum)
Minn. #1 - George Benz Sons, Inc., Shakopee
N. H. #1 - A. Hammer Cooperage Corp., Newmarket
Pa. #18 - Siboney Distilling Corp., Philadelphia (rum)
Cal. #11 - Roma Wine Co., Fresno (See IAP molasses)
Cal. #4 - American Distilling Co., Sausalito

Total production, Class (D) (7 plants) (3,885,000)

Total estimated capacity--Distilled Spirits Industry

A - 17 -- 302,900 -- 106,015,000
B - 92 -- 540,500 -- 186,690,000
C - 20 -- 33,900 -- 14,350,000
D - 7 -- 11,100 -- 3,885,000
136 -- 888,400 -- 310,940,000

Table 7.- Pre-war foreign alcohol production

Country	Data year	Production (estimated U. S. wine gallons, 190-proof)	
South American area			
Argentina	1930	5,560,000	
Brazil	1941	32,000,000	(includes beverage alcohol)
"	1942-1943	42,000,000	(of which 21,000,000 was anhydrous)
Costa Rica	1943	[illegible],730,000	(1/2 to liquor--1/2 to motor fuel)
Cuba	1942	27,000,000	
"	1944	78,000,000	(goal)
"	1945	100,000,000	
Haiti	1943	3,000,000	
Mexico	1943	12,100,000	
Nicaragua	1943	752,000	(plus 3.0 million gals. rum)
Panama	1936	222,936	(mostly used as beverage)
Peru	1936	546,000	
Salvadore	1943	200,000	(plus 1.4 million gals. rum)
Asia			
China	1937	7,400,000	(190,000,000 (goal-?) 1945)
Indo China	1938	9,200,000	
Japan	1935	794,442	(?)
"	1933	5,000,000	(150,000 metric tons of anhydrous, goal) 1944
Philippines	1936	9,650,000	
Australia	1943	26,500,000	
Queensland	1940	4,800,900	(perhaps included in Australia)
Europe			
Algeria	1938 (?)	17,300,000	
Austria	1935	5,280,000	
Belgium	1938	5,300,000	
Czechoslovakia	1938	27,000,000	
Denmark	1939	2,600,000	
England	1938	49,560,000	
France	1936	100,000,000	
"	1938	125,000,000	
Germany	1937	105,000,000	
Greece	1935	4,513,000	(11,446 metric tons in 1936?)
Hungary	1937	1,103,000	
Italy	1938	29,000,000	
Lettland	1936	2,300,000	
Netherlands	1939	14,000,000	(?)
"	1938	7,000,000	
Poland	1939	26,000,000	
Rumania	1936 (1938?)	5,800,000	
Spain	1933	21,600,000	
Sudan Africa	1938	4,800,000	
Sweden	1935	1,000,000	
Syria	1940	87,000	
United States	1945	580,000,000	(Estimated) (For comparison)
Canada	1938	7,100,000	
World total	(1938)	915,000,000	

Table 9.- Estimated costs and percentage distribution of costs of plants for producing alcohol from molasses and grain, with production of anhydrous alcohol and partial or complete recovery of byproducts

Basis 10,000 gals. per day - Pre-war cost scales.

Item	Estimated cost of item	Cost distribution (percent)					
		For 95% alcohol from molasses in base plant	For anhydrous alcohol from molasses	For 95% alcohol from grain with solids recovery only	For 95% alcohol from grain with total "grains" recovery	For 95% alcohol from grain with total recovery, including CO_2	For anhydrous alcohol from grains with total recovery including CO2
	Dollars						
Land - 10 acres at $1,000/ac.	10,000	2.5	2.3	1.8	1.5		
Services, water, sewers, etc.	20,000	5.0	4.6	3.5	3.0		
Buildings ($.50/cu. ft.)[a]	60,000	15.0	14.0	10.5	9.0		
Trackage and sidings	25,000	6.2	5.7	4.4	3.7		
Boilers - 650 hp.,@ $50.00[b]	32,000	8.0	7.4	5.6	4.8		
Raw material storage	25,000	6.2	5.7	4.4	3.6		
Yeast and fermentation equipment	60,000	15.0	14.0	10.5	9.0		
Distillation (3 columns)	60,000	15.0	14.0	10.5	9.0		
Process accessories	23,000	5.8	5.3	4.0	3.3		
Piping and instruments	50,000	12.5	11.6	8.8	7.5		
Fuel handling, water treatment and miscellaneous	35,000	8.8	8.3	6.1	5.2		
Subtotal A(for base plant processing molasses)	400,000	100.0	(92.9)	(70.1)	(59.6)	(52.0)	(50.0)
Additional anhydrous dist'n. unit	20,000		4.7	Not included	Not included	Not included	
Additional services and piping	2,500		.6				
Additional 150 hp., boilers[c]	7,500		1.8				
Subtotal B (for anhydrous dist'n. equipment)	30,000		100.0				3.7
(Accumulated total	430,000)						
Grain handling equipment	25,000			4.4	3.6		
Grinding equipment	10,000			1.7	1.5		
Cooking equipment	20,000			3.5	3.0		
Dryhouse equipment	50,000			8.8	7.5		
Services, piping, misc'l.	10,000			1.8	1.5		

(Continued on next page)

Table 9--Continued (2)

Item	Estimated cost of item	Cost distribution (percent)					
		For 95% alcohol from molasses in base plant	For anhydrous alcohol from molasses	For 95% alcohol from grain with solids recovery only	For 95% alcohol from grain with total "grains" recovery	For 95% alcohol from grain with total recovery, including CO_2	For anhydrous alcohol from grains with total recovery including CO_2
	Dollars						
Additional 300 hp., boiler[d/]	15,000			2.7	2.2		
Additional buildings	40,000			7.0	6.1		
Subtotal C (for grain-processing equipment)	170,000			100.0	(25.4)	22.0	21.3
(Accumulated total	(570,000)*						
Evaporators and accessories	45,000				6.7		
Syrup dryers	12,500				1.9		
Additional 350 B. hp., e/	17,500				2.6		
Additional building	20,000				3.0		
Additional services, piping	5,000				.8		
Subtotal D (for feed recovery equipment)	100,000				100.0	13.0	12.5
(Accumulated total	(670,000)*						
CO_2 recovery f/ equipment	100,000					13.0	
Accumulated total	770,000*					100.0	
Complete plant[g/] (including anhydrous dist'n. equipment	800,000						12.5
							100.0
Percent increase in cost over cost of base plant			7.5	42.4	67.5	92.5	100.0

a/ Fermenters outdoors.
b/ 50 pounds steam per gallon alcohol.
c/ 12 pounds steam per gallon alcohol.
d/ 25 pounds steam per gallon alcohol.
e/ 23 pounds steam per gallon alcohol.
f/ 45 percent of total CO_2 recovered in solid form.
g/ Including anhydrous distillation unit.
* Excluding anhydrous unit and accessories.

Table 10.- Processing costs for producing alcohol from corn[1]

(Basis 10,000 gallons 95-percent alcohol per day for 300-day year, or 3 million gallons per year. Required 1,149,000 bushels corn and 151,280 bushels malt. Plant cost assumed to be $750,000.)

	Assumed annual cost	Cost per gallon (cents)
Overhead, depreciation, taxes and insurance	$113,500	3.78
Salaries, management, office, laboratory	30,300	1.01
Labor and maintenance (47 men)	93,200	3.11
Office expense, bonds	7,500	.25
Water, electricity, fuel, fire protection	120,000	4.00
Chemicals and supplies (maintenance)	26,100	.87
Conversion cost, total	390,600	13.02
8 percent malt (at $1.00 per 34-lb. bushel)	151,280	5.04
Total cost, exclusive of corn	541,880	18.06
Profit allowance (nominal)		3.94
Necessary charge, for conversion and profit		22.00
Less credit for feed byproducts recovered per gallon (6 lbs. @ 1 cent per lb.)		6.00[3]
Total conversion cost (excluding corn)[2]		16.00

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[1] Tentative estimate, based on pre-war normals. Many of the items will vary with local conditions. With advantageous conditions, actual production for the labor organization might be considerably increased by relatively small increases in capital cost to provide essential equipment. With equipment of very modern design, including some automatic control features, savings of several cents a gallon might be possible. Recovery of CO_2, fusel oil, or corn oil might provide additional credits totalling 1 to 5 cents a gallon.

[2] Conversion cost from grain was quoted as 14.5-15.0 cents per gallon (1942) by F. M. Moffatt, Jr., Group Chief, Chemicals Division, War Production Board. (Hearings on S. R. 224 - (Gillette Committee) - Vol. I, p. 157.

[3] Nominal value for corn at around 50 cents per bushel. Actual credit values will vary with grain prices.