Report of

SIXTH NATIONAL CONFERENCE ON WHEAT UTILIZATION RESEARCH

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Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
Ethyl alcohol is a member of a series of related alcohols—methyl, isopropyl, butyl, and amyl—that have many and varied uses. This evaluation of ethyl alcohol concerns its production, its markets, and particularly its possible use in motor fuels.

Ethyl alcohol has been used by men since the dawn of civilization. Originally, it was produced by the spontaneous fermentation of sugars and was consumed by ancient races for its intoxicating effects. The Arabs and Romans learned to isolate the alcohol and to employ it industrially in the preparation of perfumes, cosmetics, and medicines. Over the intervening centuries the production and purification of alcohol have advanced to their present high level.

Today, production of ethyl alcohol is based on two major procedures, namely, fermentation and chemical synthesis. The most important raw materials for each procedure are as follows:

Fermentation.--Cereal grains (corn, wheat, barley, sorghum, or rye); sugarcane (molasses); sugar beets; fruit product wastes; other starch crops (potatoes or rice); sulfite liquors (paper); wood and cellulose-containing materials.

Chemical Synthesis.--Petroleum and natural gas; coal; oil shales and sands.

More than 93 percent of ethyl alcohol produced in the United States is now prepared from cereal grains or from petroleum-based raw materials (1). Synthetic alcohol from petroleum has captured practically all the industrial alcohol market of 300 million gallons or more annually. Let us compare these two major types of raw materials and their potentials.

Fermentation

Ethyl alcohol is produced by the action of yeast on the starch and sugars present in the natural raw materials. Cereal grains, including wheat, contain large amounts of starch.

Until about 1929 practically all ethyl alcohol was produced from grains, molasses, and materials high in sugar or starch. All beverage alcohol is still produced by law in the United States by
the fermentation of natural products. About 130 million bushels of grain (mostly corn, rye, barley) are used annually in this market. Grain is no longer used for industrial ethyl alcohol because it is not economical.

It should be emphasized that for industrial use synthetic alcohol is not purer or better than fermentation alcohol. Chemically, for practical purposes, both alcohols are the same.

During World War II (1942-1945) wheat significantly shared in the alcohol market (fig. 1). In 1943 alone some 100 million bushels (equivalent) were consumed, and a total of at least 250 million bushels of wheat were used during the war period. The price of wheat during this emergency was of minor importance since other raw materials, including petroleum, were in short supply, and the need for alcohol was critical. Today, only about 4 million pounds of byproduct flour (equivalent to flour from less than 100,000 bushels of grain) are used annually in the production of ethyl alcohol, and practically all of this alcohol goes into beverage use. The suitability of wheat as a raw material technically has been demonstrated by actual experience. Its use is entirely a question of economics.

The conversion of the starch and sugars to ethyl alcohol is shown in figure 2.
\[
\left( C_{6}H_{10}O_{5}\right)_{n} + nH_{2}O \rightarrow nC_{6}H_{12}O_{6}
\]
Starch \quad Dextrose

\[
C_{12}H_{22}O_{11} + H_{2}O \rightarrow 2 C_{6}H_{12}O_{6}
\]
Maltose \quad Dextrose

\[
C_{6}H_{12}O_{6} \rightarrow 2 C_{2}H_{5}OH + 2 CO_{2}
\]
Dextrose \quad Ethyl Alcohol \quad Carbon Dioxide

Figure 2.—Conversion of starch and sugars into ethyl alcohol.

Thus, 180 pounds of dextrose theoretically should yield 92 pounds of alcohol. For starch, the theoretical yield of alcohol is 0.568 pounds per pound of starch. In actual practice yields generally are about 90 percent of theoretical.

Alcohol production is directly related to the starch in the grain. If, as shown in table 1, the respective starch content of

Table 1.—Average percentage composition of surplus cereal grains\(^{1/}\)

<table>
<thead>
<tr>
<th>Grain</th>
<th>Starch</th>
<th>Protein</th>
<th>Oil</th>
<th>Fiber</th>
<th>Minor constituents(^{2/})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard wheat</td>
<td>64</td>
<td>14</td>
<td>2</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Soft wheat</td>
<td>69</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
<td>Dent corn</td>
<td>72</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Sorghum</td>
<td>71</td>
<td>13</td>
<td>3</td>
<td>2</td>
<td>11</td>
</tr>
</tbody>
</table>

\(^{1/}\) Moisture-free basis. 
\(^{2/}\) Minerals, sugars, pentosans, and vitamins.

a hard wheat and soft wheat is 64 and 69 percent (moisture-free), the maximum alcohol that could be produced from a 60-pound bushel would be 21.8 and 23.5 pounds. Translated to a 14-percent moisture basis and a practical 90-percent yield of alcohol the anhydrous alcohol obtained per bushel would be 16.9 and 18.2 pounds, respectively, or 2.58 and 2.75 gallons.

The cost of ethyl alcohol from wheat depends on many conditions, such as location, regional labor rates, and wheat used. Past studies (2) have shown that a practical-size grain fermentation plant will process about 20,000 bushels per day. Such a plant at current prices would cost about $12 million to construct. Anhydrous alcohol production would be about 17.2 million gallons from 6.6 million bushels of wheat. A representative cost estimate is shown in table 2.
Table 2.--Fermentative conversion cost of 190° proof alcohol from wheat
(Exclusive of cost of wheat)

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/gallon cents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base conversion cost</td>
<td>26.8</td>
</tr>
</tbody>
</table>
| Depreciation
  ($1.2 million/year, 10 years,
  17.2 million gal.)                           | 7.0               |
|                                                | 33.8              |
| Byproduct feed credit
  (6 lb./gal. alcohol at $52/ton)              | 15.6              |
|                                                | 18.2              |

Conversion cost of 200° proof alcohol

| Alcohol (1.048 gal. at 18.2¢)                  | 19.1              |
| Cost of dehydration                           | 1.9               |
| Total cost, exclusive of wheat, profit,       | 21.0              |
| packaging, and sales expenses                 |                   |

The wheat cost per gallon of alcohol would depend directly on the wheat price as shown in table 3.

There are other possibilities for wheat to be used to make alcohol. Conversion of wheat flour into gluten and starch and then fermentation of the starch have been considered. About 250 million pounds of flour is now processed annually to gluten (equivalent to flour from about 5,700,000 bushels). But this gluten market today is quite limited. An urgent worldwide demand for wheat gluten could possibly change the situation, at least on a limited scale. However, at current gluten prices (approximately $0.30/lb.) and markets, it is generally more economical to ferment whole grain than to convert the byproduct starch into alcohol.

Table 3.--Effect of wheat cost on ethyl alcohol cost
(Basis: 2.6 gallons 200° proof alcohol/bushel)

<table>
<thead>
<tr>
<th>Wheat price/bushel</th>
<th>Alcohol cost/gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dollars</td>
<td>Wheat</td>
</tr>
<tr>
<td></td>
<td>38.5</td>
</tr>
<tr>
<td></td>
<td>48.0</td>
</tr>
<tr>
<td></td>
<td>57.7</td>
</tr>
</tbody>
</table>

1/ These costs do not include profits, packaging, and sales expenses.
Chemical Synthesis

Practically all synthetic alcohol is now produced from ethylene, which is obtained from petroleum and natural gas. The original commercial synthetic process involved the reaction of ethylene with sulfuric acid and hydrolysis of the ethylsulfate to ethyl alcohol. The direct catalytic hydration of ethylene with water is the newer process and is increasingly used. Conversion yields of ethylene to alcohol as high as 97 percent have been reported (fig. 3).

\[
\text{Catalyst} \quad \text{CH}_2=\text{CH}_2 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} \\
\text{Ethylene} \quad \text{Ethyl Alcohol}
\]

Figure 3.--Conversion of ethylene into ethyl alcohol.

Commercial experience (3) has shown that a pound of ethylene will yield about 0.25 gallon of 190° proof alcohol. Most new synthetic plants have a yearly alcohol capacity in the order of 50,000,000 gallons. At present, such a plant would cost approximately $25 million (2). Under these conditions, the alcohol conversion costs would be as shown in table 4.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/gallon cents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base conversion cost</td>
<td>11.0</td>
</tr>
<tr>
<td>Depreciation</td>
<td></td>
</tr>
<tr>
<td>($2.5 million/year, 10 years</td>
<td></td>
</tr>
<tr>
<td>50 million gallons)</td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
</tr>
</tbody>
</table>

Conversion cost of 200° proof alcohol

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/gallon cents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol (1.048 gallons at 16.0c)</td>
<td>16.8</td>
</tr>
<tr>
<td>Cost of dehydration</td>
<td>1.9</td>
</tr>
<tr>
<td>Total cost, exclusive of ethylene, profit,</td>
<td>18.7</td>
</tr>
<tr>
<td>packaging, and sales expenses</td>
<td></td>
</tr>
</tbody>
</table>

Ethylene charges vary depending on location and included expenses.1/ The effect of ethylene price on alcohol cost is shown in table 5. To compete with these alcohol costs by fermentative production the wheat used would have to be priced at less than $0.50 per bushel.

1/ Present quoted price is 3.0 to 4.0 cents per pound.
Table 5.--Effect of ethylene cost on ethyl alcohol cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Ethylene, cents/pound</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Cost/gallon, cents</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>190° proof alcohol</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethylene</td>
<td>12.0</td>
<td>16.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Conversion</td>
<td>16.0</td>
<td>16.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Total manufacturing cost/gallon (exclusive of profit, packaging and sales expenses)</td>
<td>28.0</td>
<td>32.0</td>
<td>36.0</td>
</tr>
<tr>
<td><strong>200° proof alcohol</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethylene</td>
<td>12.6</td>
<td>16.3</td>
<td>20.9</td>
</tr>
<tr>
<td>Conversion</td>
<td>18.7</td>
<td>18.7</td>
<td>18.7</td>
</tr>
<tr>
<td>Total manufacturing cost/gallon (exclusive of profit, packaging and sales expenses)</td>
<td>31.3</td>
<td>35.0</td>
<td>39.6</td>
</tr>
</tbody>
</table>

Markets

Domestically, the market for industrial ethyl alcohol is now more than 300 million gallons per year (4). The market has been static for several years. Synthetic alcohol has captured it and raw material supplies are adequate for the foreseeable future. Can a new alcohol market be developed and, if so, can agriculture and particularly wheat share in it? The immediate consideration is the huge and growing automobile motor fuel market.

Annual consumption of gasoline for automobile fuels is about 85 billion gallons (5). Tetraethyl lead (TEL) is a major additive used in more than 97 percent of all motor fuels. Some 650 million pounds of TEL are consumed annually in the United States (3). TEL fluids increase the octane rating of gasolines regardless of the base fuel octane rating. Refinery technology has advanced since World War II so that fuels of practically any required octane rating for the latest automobile engines can be produced direct without TEL. However, ethyl fluid is still used because it is more economical to obtain the increase in this manner. Ethyl alcohol would contribute little, if any, octane increase to present motor fuels.

Lead contributes to air pollution and, from the first, its use in motor fuels has been a controversial subject. Reported toxicity threshold limit for TEL is 0.075 mg./m.³ of air (approximately 60 p.p.m.) (3). If this limit is accepted, there is a
safety factor of about 10 in the leaded gasoline vapors, and the
factor would increase several times in the burned fuel vapors.
However, with the increased emphasis on pollution control, and the
many uncertainties and controversies over TEL, its use might be
eliminated by law sometime in the future.

Ethyl alcohol has been used as a component in U.S. motor
fuels on a limited test scale only. Alcohol will give acceptable
blend and handling performance, provided the blend contains at
least 10 percent anhydrous alcohol (by volume). Lower blends
might also be used with dual and more expensive fuel systems.
The basic problem has been unfavorable economics. Legislative
action that would require the use of alcohol blends with the alco-
hol produced from cereal grains (i.e., wheat) would be required
for a significant volume motor fuel alcohol market.

The effects of such a legislative market are tremendous.
It would require more than 3.2 billion bushels of cereal grains
annually (the 1968 cereal production of wheat, corn, and sorghum
was approximately 1.57, 4.37, 0.74 billion bushels, respectively)
to produce the 8.5 billion gallons of anhydrous alcohol (10-percent
blend). This alcohol would cost more than $5.0 billion to produce
from $1/bushel grain. Approximately 500 fermentation plants with
a total capital investment in the order of $6 billion would also
be required. (Present capacity is only 15 to 20 million bushels.)
About 25 million tons per year of byproduct feed would be produced.

The significant effects of the 25 million tons of byproduct
feed produced on the markets for other grains and cereals have
not been evaluated. These high protein byproduct feeds would not
fill the gap left by removal of a high proportion of feed grain
from the market. These byproduct feeds would also compete with
such protein concentrates as soybean meal, cottonseed meal, and
other feed concentrates. Basically, there would be an excess of
protein feeds but not enough carbohydrate energy.

Opposition to the forced use of alcohol from grain in all
motor fuels by the petroleum industry and the urban population as
a whole would undoubtedly be severe. If the grain was provided
free, a 10-percent blend would add more than one cent per gallon
to the present wholesale gasoline price. Grain at $1 per bushel
would add at least five cents per gallon. TEL additive now costs
less than one cent per gallon and equivalent improvement by direct
refining would cost three to four cents per gallon.

Depletion of the world's oil and gas supplies is not pre-
predicted for a long time. Proven world gas reserves in 1967 were
estimated at about 1,000 trillion cubic feet—or about a 25-year
supply (6). Since then, the North Slope area of Alaska has been
estimated to contain some 40 billion barrels of oil and 250 tril-
lion cubic feet of gas. Other estimates place the Arctic supply at several times this amount. In addition, vast amounts of heavy oil are locked in shale and oil sands, and its recovery is under pilot study in the United States; a plant is operating in Canada. Production of pipeline gas from coal is also under pilot study.

Oil and gas costs are expected to gradually increase due to inflation, increased exploration and delivery costs, and possible international problems. The present U.S. oil price is about $3.20 per barrel (42 gallons) and in some world regions (Near East) is about $1.80 per barrel. A U.S. price in the predictable future up to $5 per barrel is possible. We could also expect the ethylene price and hence the synthetic ethyl alcohol price to increase at about the same inflation rate; however, it has not done so in the past. Present ethylene prices are 3.0 to 4.0 cents per pound and published prices are about 3.25 cents f.o.b. the production site (7).

Summary

(1) Practically all industrial ethyl alcohol now produced in the United States comes from petroleum raw materials. Synthetic alcohol costs less to produce than fermentative alcohol.

(2) Beverage alcohol in the United States must by law be prepared from cereal grains or other natural products.

(3) The production of ethyl alcohol from wheat and other cereal grains by fermentation is technically feasible and has been proven in actual operations. The alcohol is equal to synthetic alcohol in quality and performance.

(4) Use of ethyl alcohol from wheat as a required component of all automotive fuels would require national legislative action. The cost of the finished fuel would be higher than fuels now available from petroleum.

(5) An alcohol-gasoline fuel blend must contain at least 10 percent alcohol for acceptable handling and use performance. Lower blends might be used with a dual fuel system. A 10-percent blend in all motor fuels would require about 3.2 billion bushels of grain per year to produce the 8.5 billion gallons of required alcohol. Plant capital investments to produce this amount of alcohol would be at least $6 billion. Guaranteed long-term markets and stable prices would be required for such investments. Utilization of the 25 million tons of byproduct feed—which contains the original protein, but from which most of the energy has been removed—has not been evaluated.
(6) There is no predictable shortage of motor fuels or petroleum raw materials in the foreseeable future.

(7) Production of additional fermentative ethyl alcohol on a small scale from byproduct cereal fractions, or where valuable markets exist for special byproducts, may be feasible for certain isolated locations. Practically all such alcohol is now sold for beverage purposes.

Literature Cited


Note: "A Bibliography on Alcohol Production and Use of Agricultural Crops as a Source of Motor Fuels" from the Northern Regional Research Laboratory, Peoria, Illinois follows.
BIBLIOGRAPHY ON ALCOHOL PRODUCTION AND USE OF AGRICULTURAL CROPS AS A SOURCE OF MOTOR FUELS

Alcohol-Gasoline Blends


General Review Articles Dealing with Production, Use, and Economics of Alcohol


Production of Alcohol


Physical Properties of Alcohol in Connection with Its Use as a Motor Fuel


Producer Gas from Agricultural Residues


Alcohol-Water Injection


Use of Wheat in War Alcohol Program

45. The Production of Ethyl Alcohol from Wheat. Report of Conferences and Collaborative Work Undertaken by Industrial, University, and Federal Research Organizations for and With the Assistance of the War Production Board. Summarized by Northern Regional Research Laboratory, March 1944.