ments for production; barley is once again a leading candidate.

Additional fossil fuel requirements for transporting crops to fermentation facilities and for by-product recovery are very difficult to estimate for all crops. If biomass residues are used to fuel some of the preparation/distillation operations in the corn-to-alcohol system, 1 gallon of liquid fuel is gained for every 2 gallons consumed. In this instance, the energy content of the distiller's grain (expressed as liquid fuel), required to grow an equivalent amount of corn for feed, is included in the computation.

Use of biomass residues to fuel farm operations will further reduce fossil fuel requirements for production. It seems clear that replacing fossil fuels with renewable ones requires a systems approach to the utilization of biomass.

Culls as feedstock

Fruit and vegetable production practices in California cannot deliver 100 percent of the crop to market. Selection for quality necessarily rejects at least 10 percent of the reported production. Both in the field and at the packing sheds relatively large quantities of high-sugar- and starch-containing cull fruit and vegetables are a potential, low-cost feedstock for fuel alcohol. Considerably more than 10 percent of some crops, such as potatoes, melons, and tomatoes, is lost in the field or at the packing/processing plant; probably no waste is available in other crops, such as grapes and pears, because the wine and liqueur industries already scavenge for discards.

The price of culls will vary considerably; some may be gratis but it is likely that, if a fuel-alcohol industry develops in California, this resource will be quickly recognized and prices will increase sharply. Moreover, the resource may disappear!

Whatever the feedstock price, the potential alcohol production from culls is well over 10 million gallons annually. Although this represents no more than a tenth of a percent of the liquid fuels consumed in California, it can make a large contribution to fuel supplies in some counties.

Summary

Which are the candidates for fuel alcohol?—Current: barley, sugarbeet, corn, cull fruit and vegetables. Potential: sweet sorghum, fodder beet, Jerusalem artichoke.

What is the computed price per gallon?—$1.00 to $1.50.

How much alcohol can be produced annually at $1.00 to $1.50 per gallon in California?—100 million gallons from barley, 100 million gallons from corn, 120 million gallons from sugarbeet, plus more than 10 million gallons from cull fruit and vegetables at a much lower cost.

How much does this represent of total gasoline consumed in California?—Taking the total for barley, sugarbeet, and corn, more than 3 percent.

Does fuel alcohol production from these crops detract from food supplies?—No! Animal feed mixtures will be altered; sucrose will come from other sources.

Roy M. Sachs is Professor, Department of Environmental Horticulture, University of California, Davis.

The distillation of alcohol for fuel

Lynn A. Williams

Alcohols are simple chemical compounds consisting of carbon and hydrogen (hydrocarbon) chains that contain one or more added hydroxyl (hydrogen plus oxygen) groups.

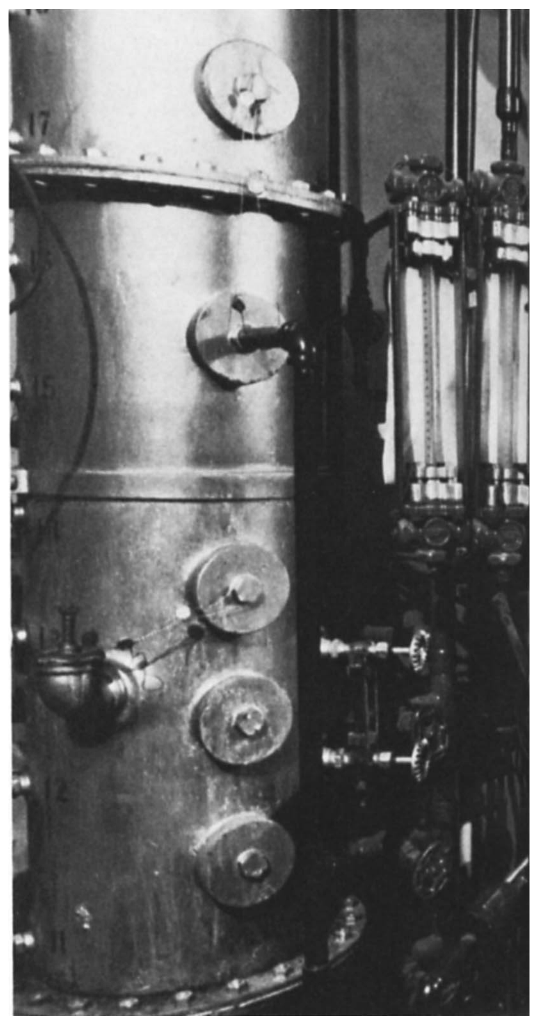
Methanol, the simplest alcohol, was previously distilled from wood but is now produced entirely chemically by the catalytic reforming of gaseous carbon monoxide and hydrogen. Most of the feedstock now comes from partial oxidation of methane (natural gas), but in the future methanol probably will be produced from coal or perhaps woody biomass by a process requiring capital-intensive high technology.

Ethanol production is one of the oldest chemical processes known to man. Early in this century the main source of industrial (nonbeverage) ethanol was fermentation, but nearly all is now produced by chemical processes under heat and pressure; the processes are based on ethylene, a petrochemical derived from natural gas or heavier petroleum fractions.

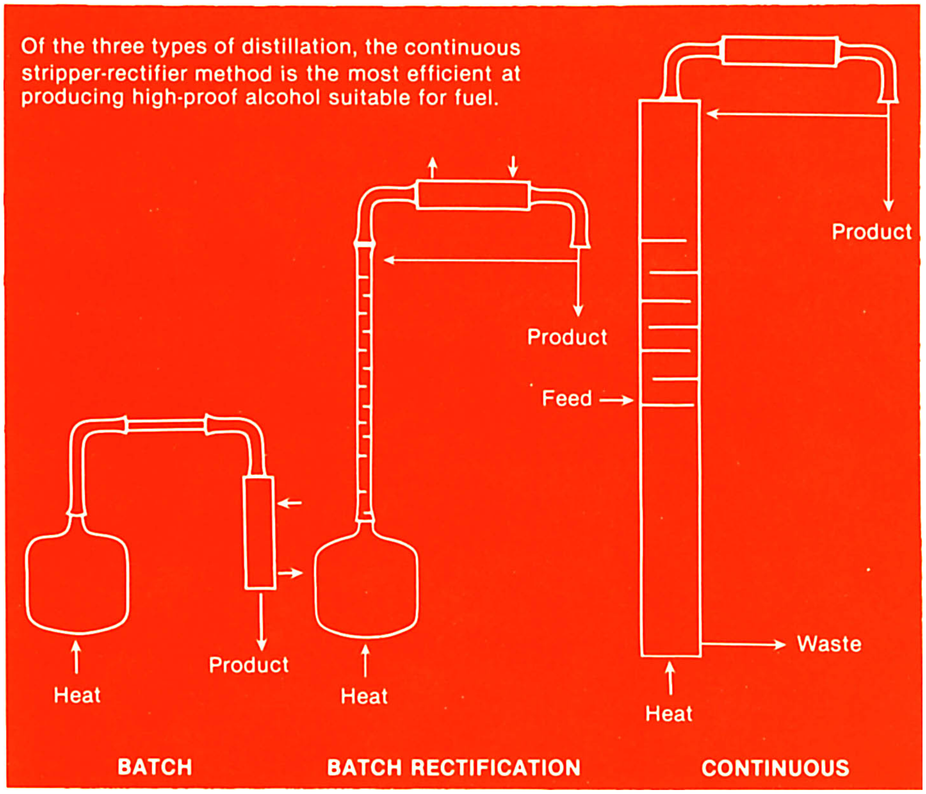
Fermentation

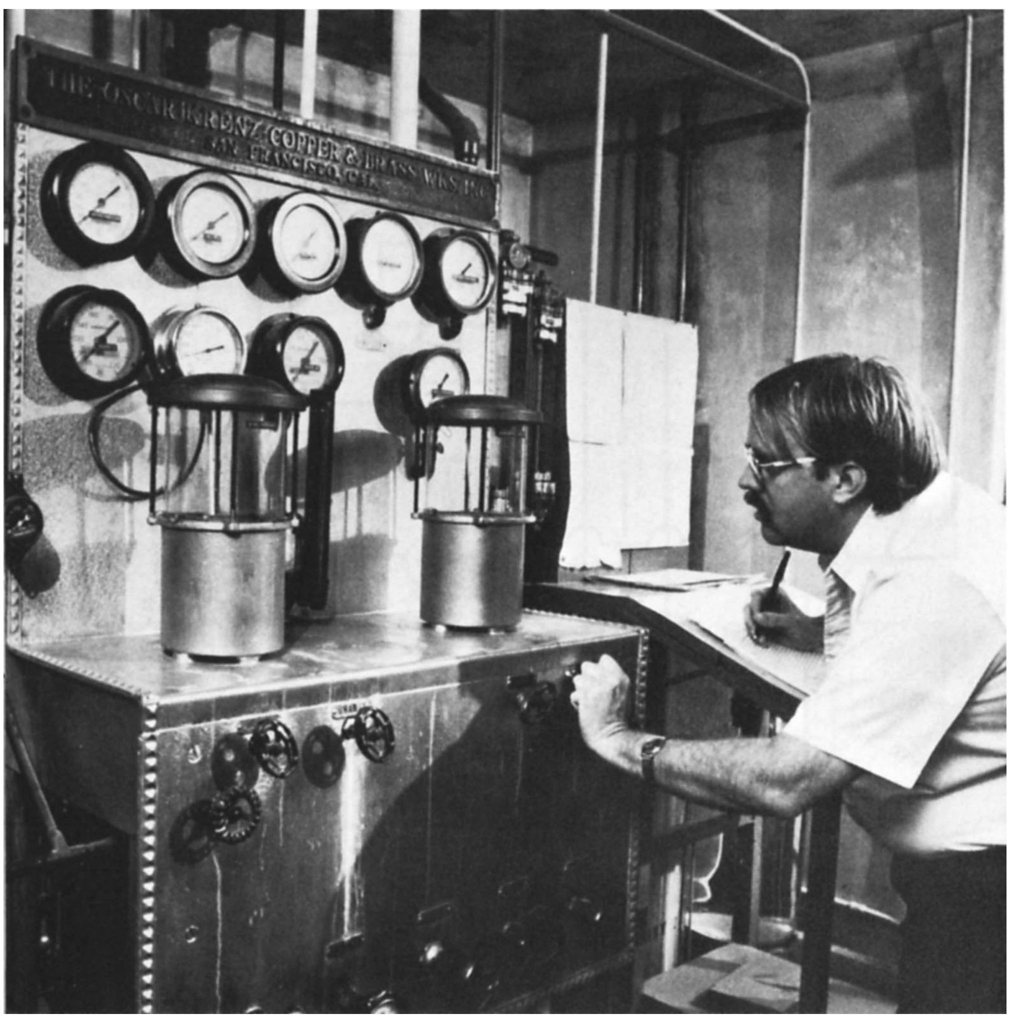
Fermentation is a simple biological conversion of sugar into ethanol and carbon dioxide. The basic materials for ethanol production are simple sugar molecules, such as glucose or fructose, found in most fruits. They are readily fermented by yeast to alcohol. Sucrose (table sugar) is a more complicated type of carbohydrate found in sugarcane or sugarbeets, but also is readily fermented.

Starch, the storage carbohydrate found in seeds, grains, and tubers, has a more complex structure and must be cooked and then broken down by enzymes or mild acid treatment before fermentation. Cellulose, an abundant carbohydrate, is more difficult than starch to break down because of the lignin content. It can be done, although the economics of cellulose breakdown are at present somewhat unsettled.



Pilot-scale continuous column still at U.C., Davis, operated here by Lynn Williams.





Distillation

Distillation is based on the fact that alcohol is more volatile than water.

In the batch type of distillation, an alcohol-water mixture is boiled in a closed pot, the vapors driven off are condensed in a heat-exchange coil, and the condensed liquid is collected. This technique produces a low-proof alcohol unsuitable for fuel. It is impossible to get complete separation with one distillation, since the vapor phase will always contain both water and alcohol. Double or triple distilling requires much more energy, and each distillation results in some loss of alcohol.

Batch rectification gives a higher proof product. The vapors from a boiling mixture pass through a series of plates (trays) in a rectifying column. Each tray is like a small boiling vessel that adds a distillation stage. The vapor becomes more and more enriched as it travels up the column and is condensed at the top. The main drawback is the batch operation, which means conditions are always changing as the pot becomes depleted of alcohol, and the proof constantly falls with time.

The most efficient distillation operation is the continuous stripper-rectifier method. Alcohol-water is fed continuously in near the center of a column containing 40 or more trays. As the liquid flows down over the trays, it is stripped of alcohol by rising vapors. By the time the liquid reaches the bottom, it should contain no alcohol. Above the feed point, the vapors continue to become enriched in alcohol at each tray as they contact alcohol-rich liquid being refluxed. The vapors leaving the top should be at maximum strength—around 95 percent by volume (near the maximum attainable for ethanol-water mixtures). A portion of the stream condensed at the top must be refluxed back into the column and the rest is the product stream.

For a 40-plate column to produce 95 percent ethanol, normally a 30- to 40-foot column would be used. Output depends on column diameter: a 1-foot-diameter column produces around 20 to 25 gallons per hour; a 6-inch column, 5 to 6 gallons per hour; and a 2-foot column, 80 to 100 gallons per hour.

Removal of the last 5 percent of water from 95 percent alcohol requires special techniques known as azeotropic distillation. This entails the addition of a third organic component, such as benzene, cyclohexane, or pentane. A pure alcohol stream exits from the bottom of the azeotrope column.

Lynn A. Williams is Assistant Professor of Enology, Department of Viticulture and Enology, University of California, Davis.