



Figure A.1. Schematic for the biostill process for ethanol production.

Ethanol can be separated from the culture vessel during fermentation using low-temperature vacuum distillation, adsorption, or membrane separations. This reduces ethanol inhibition but is seldom used in industry because of operating difficulties. Separation of ethanol from fermentation broth is usually accomplished by distillation, which is energy intensive and constitutes more than 50% of the total energy consumption of the plant. The grade of industrial ethanol is usually 95% (190 proof) for chemical and pharmaceutical use, which can be obtained by using distillation columns. However, it is difficult to obtain 100% pure ethanol, since 95% ethanol in water constitutes an azeotropic mixture. A third component is added to alcohol–water mixture to break the azeotrope, but this is expensive and the third component may be toxic.

The cost of ethanol production mainly depends on the raw material and operating costs (chiefly electricity and water cooling). Total operating cost for an ethanol plant producing 190 million liters of ethanol per year is estimated to be 42 cents/l (2001 basis). Raw materials costs constitute 26 cents/l; utilities, 3.4 cents/l; labor, 6 cents/l; and fixed charges (depreciation, taxes, insurance, maintenance), 6.6 cents/l. Plant capital investment for the same size plant is estimated to be \$71 million. Produced ethanol can be used as solvent, chemical intermediate (for production of acetaldehyde, acetic acid, ethylene), and fuel. In recent years there has been an increasing demand for ethanol utilization as fuel in

TABLE A.1. Comparison of Industrial Ethanol Fermentation Processes

	Total cycle time (h)	Ethanol concentration (g/l)	Productivity (g/l h)
Simple batch	36	80	2.2
Melle-Boinot	12	80	6.6
Continuous in series	8	86	11