This 26-foot column still designed and built by grower Neill Smith (left) near Petaluma will produce 20 gallons of ethanol per hour using Jerusalem artichoke or cheese whey as the principal feedstock. Smith and Scott Stevens (on platform) are also testing corn stover, grape pomace, and apple pomace as feedstocks.

Jack Kelly Clark

On-farm alcohol fuel production

Mark Meo □ Scott Sachs

Alcohol fuel produced from agriculture has received considerable attention from investigators and investors alike for its potential as a substitute for petroleum-based fuels, a new market for agricultural products, and a method of profitably using crop wastes and residues. Alcohol fuel, or ethanol, is produced through a two-step process of biological fermentation of starchy or sugar-rich crops to a dilute mash and its distillation in one or two vertical columns to remove the water fraction and concentrate the remaining fluid (measured by "proof").

Straight alcohol (160 to 190 proof) can be combined as a fuel in spark-ignition engines with minor modification; pure (anhydrous) alcohol (200 proof) can be mixed or blended with gasoline in concentrations of up to 10 percent (as gasohol) with no modification. Alcohol fuel can also be used to a limited degree in diesel, or compression-ignition, engines. Blends of anhydrous alcohol and diesel fuel (diesohol) can be used, but engine power and performance are impaired. Straight alcohol can be used in small amounts, but only with some modification of the engine. Therefore, common grains, such as corn, wheat, and barley, and sugar crops, notably sugarbeet, have been investigated as alternative sources of liquid fuel, as have less well known crops, such as fodder beet, Jerusalem artichoke, and sweet sorghum.

Critics have cautioned that agriculturally based alcohol fuel production is not a wise venture: that no net energy is produced; that the process, although technologically feasible, is not profitable for the farmer without subsidy; and that directing crops into fuel production will both decrease food availability and intensify degradation of soil quality. Consequently, we initiated a project to investigate the economic and energetic feasibility of alcohol fuel production. This report presents our evaluation of small-scale alcohol fuel production for partial liquid-fuel self-sufficiency on a hypothetical farm in Yolo County, California.

Method

To decide whether or not alcohol fuel can be produced from the farm's resources at a profit, the farmer must assess respective benefits and costs of all comparable options. The evaluation entails: comparing the current market value of potential feedstocks with their fermentation coproducts and the value of alcohol fuel produced; selecting a least-cost boiler fuel to purchase for fermentation and distillation; and planning for possible price increases in liquid fuels as well as in petroleum-based products such as fertilizers and herbicides. In addition, all energy inputs to the alcohol fuel production process should be accounted for and compared with the energy outputs to determine the energy credits or debits. Although generation of positive net energy is not part of the farmer's decision based on maximum profits, federal legislation specifies it as a policy goal. Furthermore, the net energy calculation supplies useful information for energy policy planning and analysis.

To place the complexity of alcohol fuel planning into a framework for systematic analysis, we used a linear programming approach. This is a mathematical technique that seeks the best solution of a problem subject to a set of constraints. In this manner, the net economic benefit (income minus costs) can be calculated for either normal agricultural production and selling activities or the diversion of crop acreage and yields into alcohol fuel.

An extension of this approach, referred to as parametric programming, allowed us to vary prices of several inputs while holding others constant. Effects of price increases in liquid petroleum fuels and their by-products can thus be compared to the net profitability of the farm. By executing a parametric procedure, we evaluated each of the most promising alcohol feedstocks, both with and without a distillation option, under several sets of prices, both current and expected.

Data sources

The simulated farm covers 1,200 acres in Yolo County—400 acres in class I soil and 800 acres in class II. The spring crop mix includes field corn, grain sorghum, sugarbeets, and tomatoes, rotated according to conventional cultural practices. The two winter crops are wheat and barley. Irrigation water is pumped from wells. In addition, crops that may be grown primarily for alcohol fuel, and thus lack an active market, include corn silage, fodder beet, Jerusalem artichoke, and sweet sorghum. Farm size, land classification, and crop mix are typical of the county and may be revised easily to fit other situations.

Figures for crop-growing activities were supplied by the University of California Budget Generator, a computerized enterprise cost data system that provides current information on requirements and costs for growing and producing farm commodities. Yields for conventional farm crops were taken from county Agricultural Crop Reports and averaged for the last five years; figures for the more unconventional and fuel crops were obtained from results of field trials conducted at the U.C., Davis, Agricultural Experiment Station in the last two years (*California Agriculture,* September-October and November-December 1981).

To evaluate potential alcohol yields from both sets of crop data, we reduced experimental yields of fuel crops slightly so that they would be comparable to yields obtained by farmers in the surrounding area. Information on crop residue availability and abundance was provided by Stanford Research Institute, Menlo Park, California. Current costs and fuel usage for harvesting, baling, and collection of selected residues were calculated by the Solar Energy Research Institute, Golden, Colorado, and the Agricultural Engineering Department, U.C., Davis.

Sources of fixed and variable costs for a small-scale distillery capable of producing up to 50,000 gallons of 190-proof alcohol annually were published literature (see table 1). Costs of setting up such a distillery are estimated as follows:

Building and fixtures	$ 23,740
Equipment and materials	50,295
Assembly and labor	33,500
Total costs	$107,535

Although a great deal of information exists on intermediate and large-scale distilleries, less is available for complete on-farm systems. Thus the costs used here are not definitive, but should be considered as examples.

Expected yields per acre of various feedstocks and conversion ratios to alcohol and by-products were obtained from published literature or through personal inquiry. In all cases, we tried to choose conservative estimates to reflect the lower probable yields that operators could expect.

An energy analysis for each cropping activity and its respective alcohol fuel conversion (table 2) counted direct and indirect process energies. Labor energy was omitted because of methodological complications and disagreement over its itemization. Direct energy costs included liquid fuel inputs, crop and residue collection energies (if used), petroleum-based inputs such as fertilizer and herbicides, and electricity. Indirect energy—that consumed to produce energy—was also accounted for as well as the energy cost of building the distillery. Energy credits included the caloric value of the crop or its residue, the fermentation coproduct, and the alcohol produced.

Alcohol production from starch and sugar-rich crops yields a variety of coproducts that may have a market value depending on size and location of the plant. In this study we assumed that, to keep costs low, the wet fermentation mash or stillage was not dried and could either be fed directly to animals or disposed of in an appropriate manner. We also assumed that the energy required to cook the starch feedstocks was roughly equivalent to that of crushing and juicing the sugar feedstocks. Available boiler fuels included coal, woodchips, and agricultural residues. Distillery operation, which would take place during the winter, would not interfere with normal planting and harvesting. For crops such as sweet sorghum and sugarbeet, whose fermentables do not store well, staggered planting and harvesting dates were assumed.

The farm model was run for eight sets of combinations. Situations of average and above-average crop yields, with and without available fermentation coproduct markets, were formulated for current prices and expected price increases in liquid fuels. For purposes of comparison, crop market prices

TABLE 1. Amortized present value of fixed costs for 50,000-gallon-per-year plant at selected discount rates for ten years.

Fixed costs	Discount rates 6%	11%	15%
Production plant building and materials	$14,631	$18,286	$21,457
Maintenance and repairs	3,584	3,584	3,584
Bonds, licensing, and fees	500	500	500
Property taxes	1,500	1,500	1,500
Insurance	1,000	1,000	1,000
Labor	1,500	1,500	1,500
ANNUAL TOTAL FIXED COSTS	$22,715	$26,370	$29,541
TOTAL FIXED COSTS PER GALLON	$0.472	$0.545	$0.608

Sources J A Atwood and L K Fischer, 1980. *Cost of Production of Fuel Ethanol in Farm-Size Plants.* Report 115. Department of Agricultural Economics, University of Nebraska, Lincoln and U S National Alcohol Fuels Commission, 1980. *Fuel Alcohol on the Farm.* Washington, D C

TABLE 2. Net energy balance for ethanol production from class II soils with average yields

Crop	British thermal units (Btu) per gallon: Distillery cost (−)	Crop input (−)	Boiler fuel* (−)	Electricity (−)	Ethanol (+)	Coproduct (+)	Net energy balance
Corn	5,478	54,490	53,333	12,928	81,000	39,584	-5,645
Wheat	↓	37,072	↓	↓	↓	32,236	4,425
Corn silage	↓	52,054	↓	↓	↓	29,310	-13,483
Barley	↓	45,021	↓	↓	↓	30,474	-5,286
Grain sorghum	↓	74,719	↓	↓	↓	34,870	-30,588
Sugarbeet	↓	79,081	↓	↓	↓	22,850	-46,970
Sweet sorghum	↓	34,569	↓	↓	↓	47,591	22,283
Tomato	↓	214,396	↓	↓	↓	13,858	-182,016
Jerusalem artichoke	↓	27,001	↓	↓	↓	2,541	-15,199
Fodder beet	↓	79,568	↓	↓	↓	47,969	-22,338

NOTE: Energy credits and debits include direct and indirect energy costs calculated from D. Pimental (ed.), 1980, *Handbook of Energy Utilization in Agriculture.* CRC Press, Boca Raton, Florida, and by the use of appropriate multipliers listed in C. Bullard, B. Hannon, and R. Herendeen, 1975. *Energy Flow through the United States Economy.* University of Illinois Press, Urbana, Illinois.

*If the crop's own residue is used as boiler fuel, there is only a slight energy debit. For example, if corn stalks were used, corn's net energy balance would be about 45,000 BTU's/gal.

were held constant as energy prices were allowed to increase.

Results

The model's selling price for ethanol and any coproduct embodies the possibility of that crop not being sold in the market. The variable costs in table 3 calculated by the model represent the breakeven prices the farmer must receive to maintain net economic returns at least constant if acreage is shifted into alcohol fuel production. Results of two hypothetical situations are shown, one with average crop yields and recent liquid fuel prices, and a second with above-average yields and projected increased fuel prices. To obtain a total breakeven cost for ethanol production, the amortized present value of the 50,000-gallon-per-year plant was added to the variable cost. The different discount rates were chosen to compare annual charges from the state low-interest loan program (6 percent) with borrowing money at 15 percent.

In both cases, the leading candidate feedstock with the lowest breakeven cost is sweet sorghum. This crop also provides the highest net energy yield per gallon of ethanol produced, produces the least-cost boiler fuel from its crushed stalks (bagasse), and increases the farm's total digestible protein by a small amount (table 4). This increase may appear to be an anomaly, but the amount of digestible protein recoverable from the wet stillage slightly exceeds the amount of digestible protein in the crop that was displaced—in this case, grain sorghum.

For average yields and November 1981 liquid fuel prices, the next most promising candidates are corn, Jerusalem artichoke, grain sorghum, and fodder beet, in order of increasing price. When yields and liquid fuel prices are higher, the ordering is fodder beet, corn, grain sorghum, and Jerusalem artichoke.

Caution must be exercised, however, in interpreting these results. First, sweet sorghum harvesting costs were obtained from experimental field trials, not from operating farms, where they may be somewhat higher; second, some difficulties in harvesting may occur, because sweet sorghum tends to lodge; and, finally, improvements in sweet sorghum harvesting technology will be necessary for widespread utilization. In addition, the results included a credit for the wet stillage or distiller's grains produced as a coproduct in the fermentation step. If this credit cannot be obtained for sweet sorghum, for example, its breakeven price would rise to $1.65 per gallon with a 6 percent discount rate and $1.79 per gallon with a 15 percent rate.

Further, the energy content of 190-proof alcohol fuel is substantially less than gasoline (124,000 Btu per gallon) or diesel fuel (140,000 Btu per gallon). Thus, 1.53 and 1.73 gallons of alcohol fuel would be required to equal 1 gallon of gasoline and diesel fuel, respectively. This calculation fails to credit alcohol fuel with any end-use energetic benefits it may obtain when used in blends, mixes, or with modified engines.

In conclusion, the farm model results indicate that fuel alcohol for on-farm use presently costs more than the purchase price of conventional liquid fuels, but with increased costs for petroleum, the situation might be different. Sweet sorghum, for example, when grown under projected conditions, can be used as a feedstock to produce energetically equivalent alcohol fuel for $1.08 and $0.58 more per gallon than the cost of purchased diesel and gasoline, respectively. The farmer may decide that the total investment benefit of obtaining partial energy self-sufficiency equals or perhaps exceeds the costs.

In addition, only 91.1 acres out of 1,200, or 7.6 percent of the total acreage of the hypothetical farm would be shifted into sweet sorghum production with just a slight diminution in total farm metabolizable energy and a positive net energy gain of almost 22,000 Btu for each gallon produced. If feedstock costs decreased in the event of spoiled crops or low market prices, alcohol fuel production from conventional crops would be more feasible economically. Total metabolizable energy from the farm in the model declines somewhat for all of the candidate feedstocks when alcohol fuel is produced, although protein-rich coproducts from corn, sweet sorghum, and fodder beet do increase the farm total of digestible protein for the case where grain sorghum acreage is displaced.

Although small-scale alcohol fuel plants operate without an economy of scale, they do not incur significant transportation or energy costs for residue collection. We are presently investigating the economic and energetic feasibility of intermediate-scale off-farm alcohol fuel production, which does require transportation of feedstocks and residues from the farm to the distillery at a greater cost. We shall also evaluate accompanying land use, nutritional, and energy balance impacts that may arise.

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TABLE 3. Costs per gallon for average and above-average yields

Feedstock	Variable cost per gal.	Fixed cost per gal.* 6%	Fixed cost per gal.* 15%	Total cost per gal.* 6%	Total cost per gal.* 15%
Average yields†	$	$	$	$	$
Sweet sorghum	1.04	.47	.61	1.51	1.65
Corn	1.38	↓	↓	1.85	1.99
Jerusalem artichoke	1.45			1.92	2.06
Grain sorghum	1.47			1.94	2.08
Fodder beet	1.64			2.11	2.25
Above-average yields ‡					
Sweet sorghum	.91			1.38	1.52
Corn	1.38			1.85	1.99
Jerusalem artichoke	1.54			2.01	2.15
Grain sorghum	1.47			1.94	2.08
Fodder beet	1.18			1.65	1.79

*Costs at 6 percent state low-interest loan and at 15 percent rate.
†Diesel fuel at $1.15 per gallon, gasoline at $1.31 per gallon (November 1981 prices).
‡Diesel fuel at $1.30 per gallon, gasoline at $1.46 per gallon.

TABLE 4. Total farm nutrient production with and without alcohol fuel production at different crop yields

Crop	Total metabolizable energy	Total digestible protein
Average yields	× 10^7 Btu	tons
No alcohol produced	3.936	283
Alcohol (50,000 gal.) produced from:		
Sweet sorghum	3.659	284
Corn	3.633	304
Jerusalem artichoke	3.752	273
Grain sorghum	3.422	295
Fodderbeet	3.734	281
Above-average yields		
No alcohol produced	5.058	349
Alcohol (50,000 gal.) produced from:		
Sweet sorghum	4.828	352
Corn	4.721	368
Jerusalem artichoke	4.825	337
Grain sorghum	4.533	362
Fodderbeet	4.886	349

SOURCES: Crop and fermentation wet stillage and distiller's grains nutrient composition were taken from R. A. Nathan, 1978, *Fuels from Sugar Crops*, Battelle Columbus Laboratories, and from National Academy of Sciences, 1971, *Atlas of Nutritional Data on United States and Canadian Feeds*, Washington, D. C.