MASTER

Report 305-100-02

THE POTENTIAL FOR CROP DRYING WITH GEOTHERMAL HOT WATER RESOURCES IN THE WESTERN UNITED STATES: ALFALFA, A CASE STUDY

A paper presented to the
NATO-CCMS Conference on the Economics
of Direct Uses of Geothermal Energy
Department of State
Washington, D.C.

by

Thomas C. Wright

THE FUTURES GROUP
124 Hebron Avenue
Glastonbury, Connecticut 06033
(203) 633-3501

June 22, 1977

DISCLAIMER

THE POTENTIAL FOR CROP DRYING WITH GEOTHERMAL HOT WATER RESOURCES IN THE WESTERN UNITED STATES: ALFALFA, A CASE STUDY

Thomas C. Wright*

Abstract

Preliminary results of engineering, economic, and geographic analysis of the use of low-temperature geothermal heat for the commercial drying of grains, grasses, fruits, vegetables and livestock products in the United States are reported. Alfalfa (lucerne) dehydration was chosen for detailed process and cost study.

Six different geothermal heat exchanger/dryer configurations were examined. A conveyor type that could utilize geothermal hot water for its entire heat requirement proved to be the most economical. A capital cost estimate for an all-geothermal alfalfa dehydration plant near the Heber Known Geothermal Resource Area in the Imperial Valley, California was prepared. The combined cost for heat exchangers and dryer is about $1.6 million. Output is about 11 metric tonnes per hour.

Acreage, production and dollar value data for 22 dryable crops were compiled for the areas surrounding identified hydrothermal resources in 11 western states. The potential magnitude of fossil fuel use that could be replaced by geothermal heat for drying these crops will be estimated.

Introduction

The overall objective of this study is the analysis of the application of moderate temperature geothermal heat (90 to 150 degrees Celsius) to commercial drying of grasses, grains, and selected fruits, vegetables, and livestock products. A detailed engineering and cost analysis is being performed for a geothermal alfalfa dehydration process. We will compare geothermal energy costs with those of present energy sources and with the risks of natural gas curtailments. The regional and national impacts of geothermal drying for agribusiness, other interest groups, and the public in general will be evaluated. Finally, we will recommend policies designed to optimize these impacts. This study is being performed under U.S. Government Contract No. EG-77-C-07-1628 for the Division of Geothermal Energy, U.S. Energy Research and Development Administration.

We address two main questions with this study. First, is the drying of alfalfa technically and economically feasible with moderate temperature

*The Futures Group, 124 Hebron Avenue, Glastonbury, Connecticut 06033 U.S.A.

geothermal energy? The second question is more general. What crops are located near identified moderate temperature geothermal resources, and for which of these crops are the drying processes suited to geothermal heat?

Alfalfa dehydration was selected for analysis for several reasons. Alfalfa hay is among the ten most valuable crops on the basis of gross receipts by growers in all of the eleven continental U.S. states west of and including Montana, Wyoming, Colorado, and New Mexico. Alfalfa dehydration is an energy-intensive process: about 10 Gigajoules (GJ) per metric tonne are required to dry fresh-cut "green-chop" from 75 percent initial moisture to the 10 percent moisture "dehy" product. Alfalfa dehydrators represent an important drain on natural gas supplies within the drying industries. U.S. dehydrators annually burn about 10 million Gigajoules (10^{16} joules) or 10 trillion BTUs of natural gas. Finally, the alfalfa dehydration industry has suffered cutoffs in natural gas deliveries in some locations; these threaten to become widespread and frequent. Based on these considerations, our study addressed both the retrofitting of present dehy plants and the construction of new ones located near identified geothermal areas.

The Conventional Alfalfa Dehydration Process

The following is a description of the standard process used to produce dehydrated alfalfa meal, usually pelleted for ease in handling and feed mixing:

> Green-chop alfalfa is trucked from independent growers' fields with the moisture content ranging from 70 to 90 percent, depending on weather conditions. This moisture content must be lowered to approximately 7 to 10 percent in order to prevent spoilage; elapsed time between harvesting and dehydration must not exceed about two hours. This consideration, as well as transport costs, dictates a normal distance of 15 to 20 kilometers between the fields and the dehy plant.
>
> An automatically controlled rotary flame furnace fired by oil or natural gas supplies the necessary heat for the drying process. Hot gases pass directly from the combustion chamber through the intake tube and enter the inner drum cylinder at a temperature ranging from 500 to 1000°C depending upon the moisture content of the material to be dehydrated (650°C is typical).
>
> The material to be dried is chopped or shredded and fed into the suction-sealed feed conveyor, which conveys it into the receiving hopper of the intake tube.
>
> The drum unit usually consists of three concentric drying cylinders into which the hot gases and the material to be dried enter by way of the intake tube. The material is then advanced through the drying drum by means of a suction fan. The three cylinders are concentrically arranged, mechanically interlocked, and rotate at the same speed. The material is repeatedly carried to the top of each cylinder by the cylinder flights and dropped through the

hot gases, giving off moisture as it passes progressively forward through the inner cylinder, then back through the intermediate cylinder, and forward again through the outside cylinder to the suction fan at the discharge end of the machine. With this type of concentric cylinder construction, the material is exposed to the drying medium for about 20 meters, ensuring complete utilization of heat through radiation from each cylinder. Retention time in the dryer is no more than two to three minutes.

After the material passes through the drying drum, it is blown into the large drying collector, where the vapor-laden air at about 120°C escapes out of the top, and the dried material passes into the cooling hopper and gravity separator, where the foreign materials are removed. A second fan propels the material into the cooling collector where it swirls downward into the sacking pipes or the hammermill for pelleting, as may be desired.

After cooling, the pellets may be stored in tanks at below-ambient temperature or in inert gas to prevent spoilage. Shipment to distant markets is by rail--to the Eastern U.S. from the Midwestern producers or to port for export to Japan from Western dehydrators. Local delivery is by truck.

The normal operating season in the Northern Plains (Kansas and Nebraska are states that produce the most dehy) extends from about May through October. All-year operation is possible in the Imperial Valley, California due to favorable climate and irrigation. Dehydrating units range in size, but new plants most commonly produce about 3 dry tonnes per hour. Several dryers of this size are used when larger capacities are required. Annual production may range from 5,000 to 50,000 dry tonnes per year. The load factor, or proportion of capacity over time that is actually utilized, appears to range from about 30 to 50 percent.

The cost of natural gas to dehydrators varies substantially at different locations. Costs ranging from $10 to $20 per dry tonne were quoted during interviews with Western dehydrators. These costs represent 10 to 20 percent of the finished product price.

It can be seen that the temperatures required for the conventional alfalfa dehydration process are a good deal higher than those of moderate temperature geothermal resources. Before the techniques with which we proposed to cope with this problem were defined, another question was addressed: How far can geothermal hot water of about 150°C be piped to a dehydrator at reasonable cost? One can assume that present dehydrators would wish to retain existing sources of supply for green-chop alfalfa after conversion to geothermal heat. Prospective dehydrators would wish to locate as near as possible to prospective suppliers. A knowledge of the cost of geothermal heat with respect to pipeline length would enable a dehydrator to trade off raw alfalfa transportation cost with energy cost to determine whether he could remain in his present location and convert to geothermal, or if not, where the optimum location might be.

Heat Transmission to the Dehydrating Plant

Two studies were undertaken in the early portion of this study toward the design and costing of systems to deliver geothermal hot water to dehydration plant sites. The first study was a parametric analysis of piping costs for three different plant heat loads. The second utilized the geocost fluid transmission submodel developed at Battelle Pacific Northwest Laboratory.

For the parametric analysis, an alfalfa dehydration plant that requires about 15 GJ/hours to produce 3 tonnes/hours of dried alfalfa was assumed as a base case. Heat demands of 50 and 100 GJ/hours were also considered in order to assess the effect of scale on costs. Given a geothermal water rejection temperature of 49°C, the required inlet temperatures to the first water-isobutane heat exchanger were calculated. (A second isobutane-air exchanger is required in this design.) These inlet temperatures were established by specific geothermal water flow rates. The flow rates were set by assuming use of the "economic velocity" (1.7 meters per second) through the range of standard schedule-40 steel pipes sizes from 4 to 16 inches (10 to 40 cm) in diameter. Knowing pipe diameter, and assuming 5 centimeter polyurethane insulation and a 14°C soil temperature, the required wellhead temperature could be calculated as a function of distance. Well cost was $400,000 and maximum production was about 38 liters/second of hot water. An equation* gave capital cost of the production and reinjection well system. One reinjection well for each two supply wells was assumed. Field development costs beyond actual drilling and hardware were set equal to the cost of one well. No costs were included for geophysical exploration and the like--a developed field was assumed.

Another equation estimated the capital cost for the pipeline and booster pumps as a function of pipe diameter and length. Total capital cost up to the heat exchanger is given by the sum of the cost of the production/reinjection system and the pipeline system. Annual operating cost for the combined system was then derived, assuming 10 percent per year well replacement, 30-year straight-line depreciation at 8 percent interest, and non-profit operation. Finally, the cost of heat in dollars per Gigajoule was computed assuming 50 percent duty as a base case (4,380 hours per year operation; 25 percent duty is more typical today in the Northern Plains states).

For the GEOCOST simulation, very similar assumptions were made for the "base case" run except that only one estimate of heat demand, 15.7 GJ/hour, was used. The wellhead temperature parameter was varied from 66°C to 204°C in a series of five variations from the base case. Transmission lengths of 1.6, 32.2, and 80.5 kilometers were tested and the options of no reinjection and public financing (thus eliminating most taxes) were tried in other runs.

Table I gives the costs as shown by the parametric study for heat transmission to the dehydration plant site and for heat exchange. The plant is assumed to be located at the site of a geothermal source of 132°C so that pipeline cost is near zero. About $.53 per kilometer must be added to the energy cost for the 15 GJ/hour plant for pipeline transmission; for a 50 GJ/hour heat load, about $.22 per kilometer.

---

*Bernard B. Basse, "The Thermal Systems Model," Paper X, Susanville Geothermal Energy Project: Workshop Proceedings/Final Technical Report, ERDA Report SAN-1077-4 (July 13, 1976), p. X-2.

Table I

CAPITAL AND ENERGY COSTS
FOR HEAT TRANSMISSION AND EXCHANGE

	DEHYDRATION PLANT HEAT DEMAND		
	15 GJ/Hour	50 GJ/Hour	100 GJ/Hour
CAPITAL COST (1975 U.S.$)			
a. For production-reinjection well system	$1,262,160	$1,262,160	$2,045,176
b. For heat exchangers	406,000	811,000	1,345,000
c. Total (a & b)	1,668,160	2,073,160	3,390,176
ENERGY COST ($/GJ)			
d. For production reinjection well system	$5.44	$1.63	$1.21
e. For heat exchange	1.40	.84	.69
f. Total (d & e)	6.84	2.47	1.90

The energy cost for a 15.7 GJ/hour demand as estimated by the GEOCOST base case run agreed quite well with the 15 GJ/hour result of the parametric analysis. GEOCOST predicted an energy cost, less heat exchange, of $12.84/GJ for 16 kilometer pipeline transmission; the parametric study showed a cost of about $13.49. When pipeline length was 1.6 kilometers, GEOCOST estimated $6.30; the parametric analysis, $6.24.

Two main conclusions were drawn from these analyses of geothermal hot water transmission. First, if well costs are in the $400,000 range as we assumed, it is not feasible to pipe the geothermal water more than a few kilometers if energy cost is to be comparable to present natural gas or fuel-oil cost. It follows that only a few existing dehydration plants are likely to be near enough to identified geothermal areas to permit geothermal retro-fitting.

Preliminary Assessment of Geothermal Dryer Options

Several methods for utilizing moderate temperature geothermal heat for alfalfa dehydration were evaluated. Geothermal hot water might pre-heat air which is then raised to the conventional rotary drum inlet temperature of 500 to 1000°C with natural gas combustion. Or a heat pump could be used to raise the temperature available from geothermal fluids to about 500°C, enough to eliminate the need for fossil fuel combustion. The rotary drum dryer with its present high inlet temperature would be retained for either of these methods. More plausibly, one could seek a dryer design capable of utilizing geothermal energy at the delivered temperature for the entire drying requirement.

The first method seems entirely feasible but may well be uneconomic. At a geothermally pre-heated air temperature of 150°C only about 15 to 30 percent of the natural gas requirement would be eliminated. The overriding problem of natural gas curtailments would still exist and the need for locating the dehydration plant near a natural gas pipeline would remain. Also, investment in a high cost, high output geothermal well would be underutilized.

The concept of a large heat pump, or several of them in series, to boost the temperature available from geothermal hot water resources several hundred degrees Celsius was studied and rejected for serious consideration in our project. Several heat pump manufacturers were contacted but none knew of an available or prototype unit capable of boosting heat flows on the order of 15 to 100 GJ/hour to the required temperature of 500°C or so. Working fluids that could operate at such high temperatures are not available; heat pumps would probably have to be cascaded to achieve such large temperature changes and would thus be extremely inefficient in any case.

Two possible approaches to low temperature drying of alfalfa were examined. One might adapt conventional rotary dehydraters to use low temperature heat at the inlet. Or, one might use a different type of dryer especially designed for low temperature operation. A computer model that permits the simulation of rotary drum dehydrator operation at a variety of inlet and outlet temperatures, drum lengths, and drying times has been used to examine the first option. We concluded that such a drum would have to be prohibitively long in order to permit alfalfa drying to 10 percent moisture content. Drum lengths on the order of hundreds of meters were indicated by the model, clearly an impractical solution.

The most feasible dryer appears to be a unit similar to that used by Broadlands Lucerne Co. in New Zealand. A brief description of this dryer follows, based on information given to us by Mr. Ken Pirie of Fisher and Paykel Engineering Company, designer of the plant. The preliminary design and cost of a scaled-up unit for operation in El Centro, California within the Heber Known Geothermal Resource Area is presented in a later section.

The plant, located about 55 kilometers south of Rotorua in the Broadlands geothermal field, is owned by a cooperative of a dozen farmers who grow lucerne on the eastern side of the Waikato River. Geothermal wells of the Broadlands field are dotted within this farmland.

The dryer is a fixed bed, double-pass, drag conveyor type. The bed is louvered to permit the air stream to pass up through the alfalfa from below. The conveyor system is 30 meters long, composed of two 15 meter sections 2.4 meters wide. The wet alfalfa is first carried up an input conveyor and into the first section. It is dropped onto the second section, further dried, and then moved with an auger material-handler to the hammermill and pelletizer. The airstream from below nearly "floats" the alfalfa above the bed in a pile 40 centimeters deep.

The heat exchanger is a steel fin-tube type, a coil eight rows deep, galvanized on the outside, 2 fins/cm. A total of 1,400 square meters of surface area is used. This was thought to be a conservative, but the geothermal steam is 20 percent by volume incondensable CO_2 so that the coil should be 20 percent larger. Only slight problems with silica scaling have been encountered.

Dry geothermal steam is fed into the coil exchanger at 177°C. The pressure is constant at 10.3 bars (150 pounds/square inch). Ambient air (16 to 27°C) is passed over the coil and heated to 93 to 143°C. Air flow rate is variable from 19.8 to 23.6 cubic meters per second to permit different initial moisture contents in the alfalfa input. The inlet moisture of the alfalfa varies from 65 to 85 percent at the end of summer and in early spring, respectively. The alfalfa is slightly wilted during harvesting and transport. The outlet moisture content of the alfalfa ranges from 8 to 12 percent and usually is about 10 percent. Outlet air temperature is 49°C dry bulb, 32°C wet bulb. Alfalfa throughput is about 1 tonne/hour on a dry weight basis (5 tonnes/hour wet basis). Annual production is 1630 tonnes dry pellets, but much more is possible.

Initially we were concerned that poor product quality might result from drying at temperatures of about 150°C due to the lengthened retention time required (45 minutes as compared to two or three minutes in a conventional drum dryer). Available experimental data was insufficient to show whether low temperature drying might permit destructive enzyme action to take place. Laboratory experiments to enable us to analyze the effects of lowered temperatures and increased drying times on product quality were too expensive for inclusion in this study. Fortunately the Broadlands Lucerne Company plant is operating with drying conditions similar to those that our low temperature dryer design would require. An analysis of the dehy product from the Broadlands plant shows product quality comparable with that currently standard in the Western United States. We are therefore reasonably sure that the alfalfa produced by the low temperature dryer design discussed below would be marketable and of good commercial grade.

Table II

OPERATING DEHY PLANTS IN THE WESTERN UNITED STATES AND IDENTIFIED GEOTHERMAL RESOURCES

Map No.	Dehy Plant Location	Nearest Geothermal Resource (s)	Distance (km)
1	Yuma, AZ	Dunes KGRA, CA	40
2	Dixon, CA	(Jackson's) Napa Soda Spring Napa Soda S. Rock (Priest)	40 40
3	Clarksburg, CA	(Jackson's) Napa Soda Spring Napa Soda S. Rock (Priest)	55-65 55-65
4, 5	Firebaugh, CA	Mercey Hot Spring	40
6	Bakersfield, CA	Sespe Hot Springs	90
7	El Centro, CA	Heber KGRA	4
8	Holtville, CA	East Mesa KGRA	10
9	Twin Falls, ID	Hot well near Cedar Hill	20
10	Dexter, NM	Radium Hot Spring	250
11	Hagerman, NM	Radium Hot Spring	250
12	Irrigon, OR	Ritter Hot Spring	110

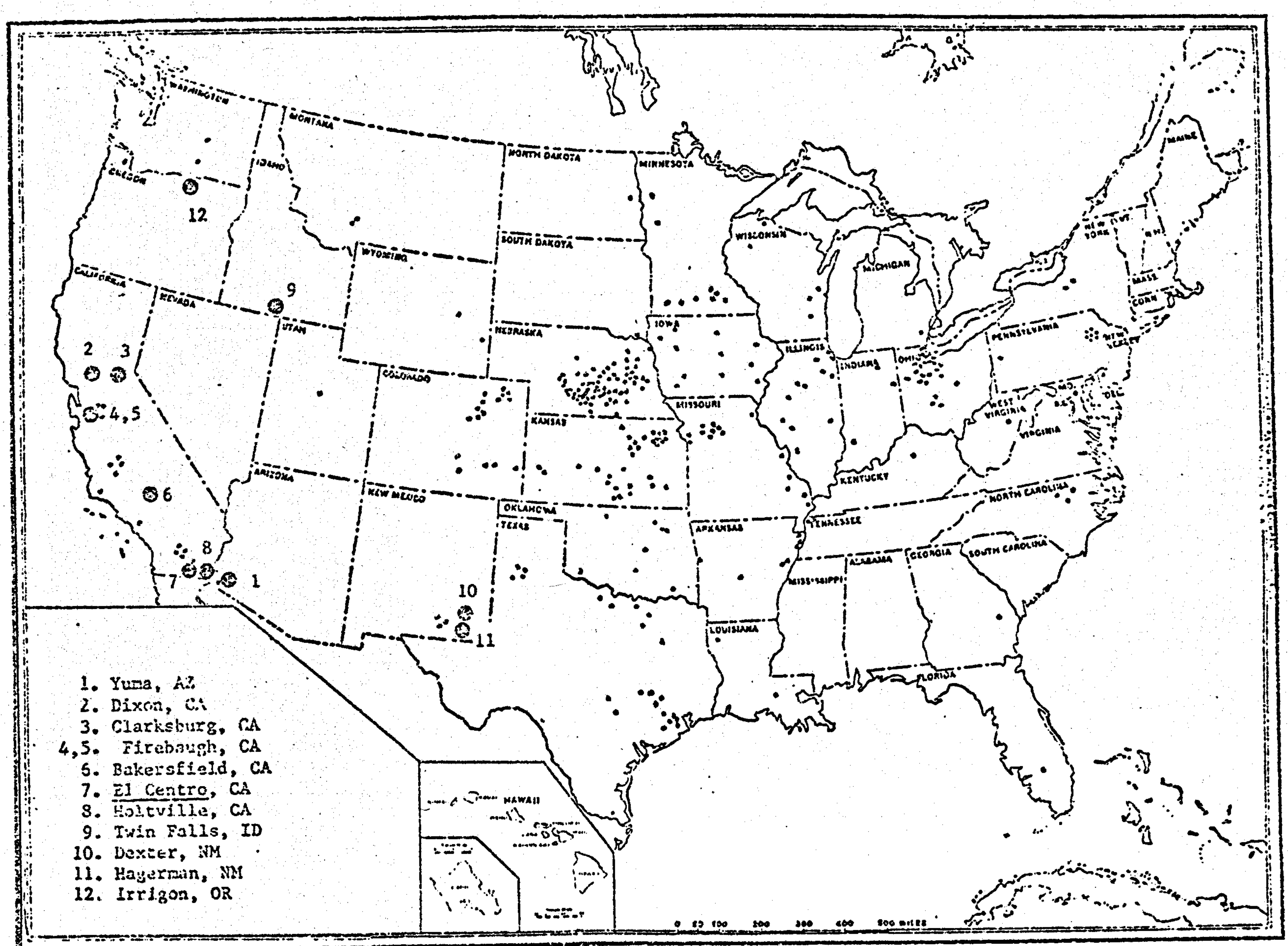

Figure 1. Distribution of dehy plants in the United States.

Market and Institutional Characteristics of the U.S. Dehydrated Alfalfa Industry

The rapid expansion of the dehydrated alfalfa industry during the 1940's and early 1950's was stimulated by the promotional efforts of natural gas companies seeking an outlet for gas sales during their summer off-peak season. Natural gas continues to be the principal source of energy for dehydration of alfalfa, though promotional activities have ceased due to recent shortages of supply of natural gas. By and large, the industry has tended to locate where natural gas supplies were available and where gas consumption patterns fit in well with the growth period for alfalfa.

There are estimated to be about 250 dehy plants in the country, concentrated largely in the Midwest (see Figure 1). In the far west, California with about eight plants known to be active, leads the other states. Oregon, Idaho, Arizona, and New Mexico have one or two plants each. (Colorado also has about a dozen plants, all located in the eastern part of the state, remote from geothermal resources.)

Current annual U.S. production of dehy is about 1.2 million tonnes, down from a peak of 1.6 million tonnes in 1970. The dehy produced in the Midwest is purchased by local feed formula manufacturers and livestock feedlots (within a radius of 150 to 300 kilometers of each plant) or shipped to the large feed companies in the East. California's market had been dominated by exports to Japan. The recent decline of Japanese purchases in the United States because of the competition of Canadian dehy, however, has had a serious impact on the California dehy industry. Shipments to Japan, which ran as high as 231,000 tonnes in 1971, were down to 46,000 tonnes in 1976.

The industry may have excess capacity at present. The loss to Canada (where dehy production has been promoted and partially subsidized by the government) of much of the foreign market is probably permanent. The domestic market dehy competes on a cost per nutrient basis with other feed formula ingredients. Though it is valued in poultry as a pigmenting agent, its low-energy, high-fiber content limits the amount that can be mixed into feed rations. A relatively stable market is felt to exist at about the current production level, provided production costs (energy, labor, and price of greenchop) do not escalate faster than the prices for other feedstuffs.

Based on the discouraging prospects for growth of the alfalfa dehydration industry, we decided to concentrate on the retrofitting of existing plants near geothermal areas rather than the construction of new plants. Figure 1 and Table II show that there are about a dozen plants known to be operating in the vicinity of identified geothermal resources. Only three of these plants are within 20 kilometers of such resources. Local, and not national, impacts on agribusiness and energy consumption are to be anticipated from geothermal use for alfalfa dehydration.

Site Specific Analysis of Geothermal Alfalfa Dehydration

Our objective in performing a case study for a particular geothermal resource and a particular existing dehydration plant is to integrate all of the technical and economic elements of geothermal delivery systems and the alfalfa dehydration process in order to examine them as parts of a system. This integration will allow consideration of cost trade-offs, for example, the cost of hauling alfalfa versus pipeline transmission cost. We are performing this analysis for an active dehy operation near El Centro, California in the Imperial Valley geothermal area. We may also examine a smaller operation near a geothermal resource in the Twin Falls area, Idaho. These two sites were chosen partly because they span a wide range of plant operating conditions, dehy markets, and geothermal resource types. Moreover, these dehy plants are two of the three in the U.S. that are within 20 kilometers of identified moderate temperature hydrothermal systems. (The third plant is located in Holtville, California, near the East Mesa Known Geothermal Resource Area, a high-temperature resource.) If geothermal retrofitting is not feasible for either of these two locations, one may infer that it will not be feasible for any U.S. location.

We have secured the conditional cooperation of the operators of these plants for our study. The operator of the plant in El Centro, California has indicated that he would be willing to cooperate further if the preliminary costs for geothermal energy and new drying equipment are attractive. Should the initial costs for energy and dryer modification or replacement be unattractive to the operators, the case studies will conclude with assessments of which costs were excessive. Should the initial capital and energy costs be within plant investment and operating expense capabilities, more detailed analysis of geothermal retrofitting will be performed. The operator of the El Centro plant has indicated that a geothermal energy cost per Gigajoule of up to 50 percent more than the present cost for natural gas might be feasible if geothermal use permitted him to operate without interruption. He could thus take advantage of favorable prices for alfalfa at any time and be able to guarantee his supply or make firm contracts for delivery of his product.

The El Centro dehydrating plant is located on a rail siding about one-half kilometer south of an interstate highway and four kilometers southeast of the center of the city of El Centro (see Figure 2). Across the road to the north of the dehy plant is the Valley Nitrogen Plant, a fertilizer manufacturer, and subject of one of the site-specific non-electric studies being performed under contract to the U.S. Energy Research and Development Administration. Three miles to the south of the dehydrating plant is the center of the Heber anomaly with its concentration of geothermal wells.

The dryers consist of two 8200 kg/hour (evaporative capacity) drums and two 10,000 kg/hour drums. The four drums together can produce about 9 dry tonnes/hour of 12 percent moisture, 17 percent protein dehy--this is quite a large plant. All dehy is exported to Japan, which is part owner of the plant, for use in poultry feeds. Dehy production accounts for about 50 percent of the plant business; the remainder is cheaper sun-cured alfalfa for local markets. The export market is supplied via rail and the port of San Diego; the local market, all within a 400 kilometer radius, is supplied by truck.

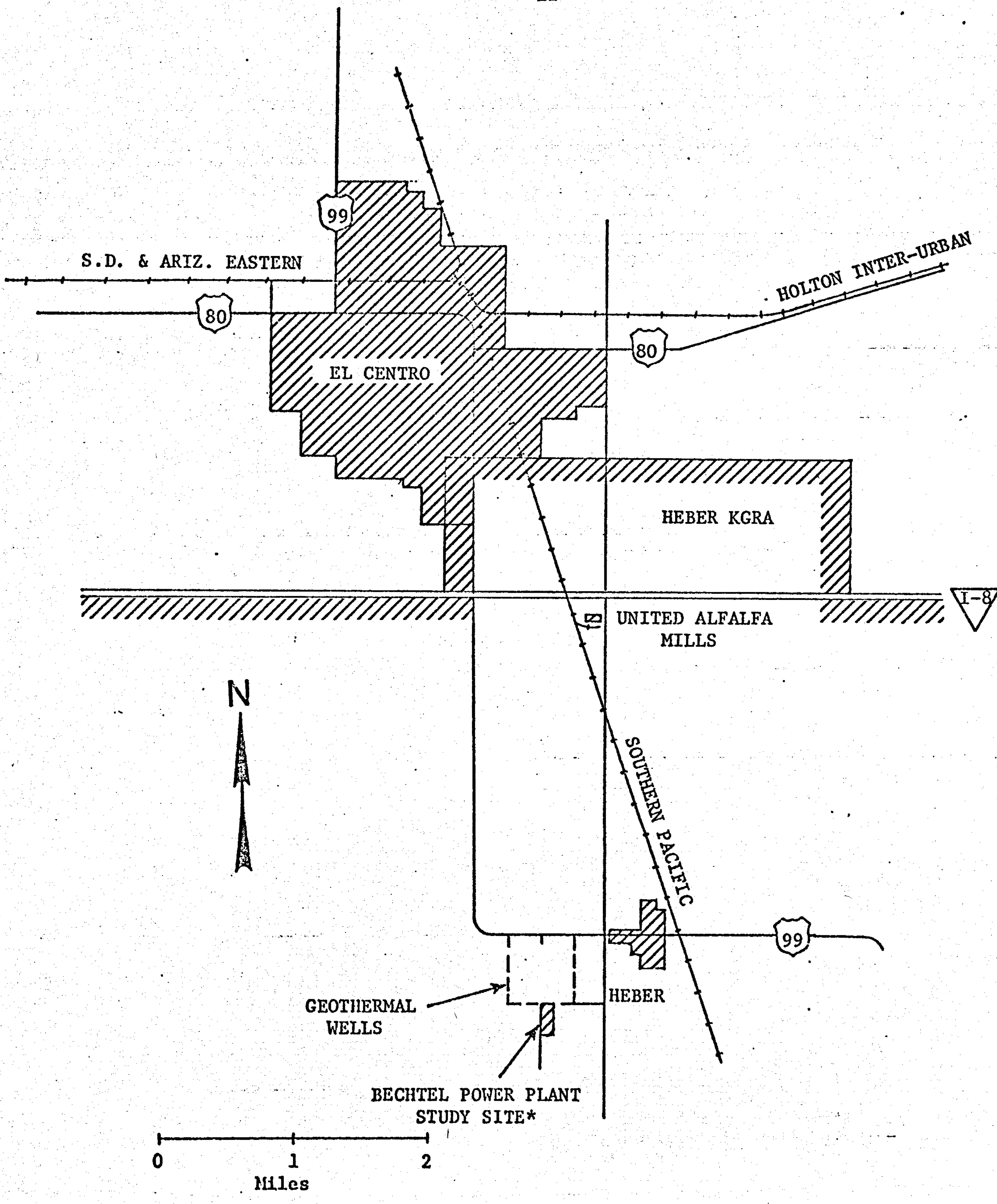

Figure 2. El Centro dehy plant and Heber KGRA.

Green-chop alfalfa is delivered in plant-owned trucks from independent growers mostly within 15 kilometers of the plant. Perhaps 20 percent of the alfalfa is from farms 15 to 30 kilometers away. The climate and irrigation permit eleven cuttings of alfalfa annually for a year-round plant operating season.

The operator is worried about the rising cost and declining availability of natural gas. His cost for gas is $12 to $13 per tonne of dehy at present, and gas was curtailed recently for four days. The use of stand-by fuel oil would increase the energy cost per dehy ton greatly. With his present energy sources a long gas curtailment or a significantly higher price for gas would make dehy production untenable.

Unlike most dehy operators, the operator of the El Centro plant was optimistic about his market. He felt that California could export more tonnage to Japan than it now does. Because cost is his main concern and not marketing, he is willing to consider a sizeable investment in geothermal energy if the unit energy cost is not much higher than the present natural gas cost.

Preliminary engineering designs for two types of geothermal alfalfa dryers have been prepared for a plant scaled to present peak production capacity for the El Centro plant, about 12 tonnes/hour. A flow diagram for the first heat exchanger-dryer combination is shown in Figure 3. This system utilizes a turbine-driven compressor to drive a heat pump that in turn generates pre-heated air at about 240°C. The turbine is driven by the expansion of the isobutane secondary fluid; heat for expansion is geothermal. The isobutane turbine unit is commercially available as a "Magmamax." Five heat exchangers are required for the entire system, making it quite expensive: $3 to $5 million is the estimated cost of equipment for this system, excluding compressor, process heat exchanger, condenser and process pump requirements.

Figure 4 shows the conveyor-type dryer about which we are more optimistic. The drying equipment consists of four conveyor units each about 30 meters long. Total dryer cost is estimated at about $900,000.

The heat exchanger for this system (not shown) is a counter-current shell and tube type with a geothermal hot water primary circuit and process air secondary circuit. The energy requirement for our preliminary design is 123 GJ/hour to heat 303 kilograms/second of 21°C air to a dryer inlet temperature of 138°C. The required brine flow at an exchanger inlet temperature of 149°C with 71°C return is 116 liters/second. The estimated cost of the heat exchanger is $700,000 based on the use of type 304 stainless steel tubes and aluminum fins.

We plan to explore the cost of geothermal energy delivered to the heat exchanger with the aid of the GEOCOST program for three plant operation alternatives. The first option would be operation of the plant at its present location utilizing its own pipe line. A second option would be a shared pipeline with the Valley Nitrogen Plant just across the road from the dehy plant. Energy consumption by the Valley Nitrogen Plant is significantly higher than for the alfalfa plant. Therefore it is likely that a shared pipeline might significantly decrease the cost of delivered geothermal energy to the dehy

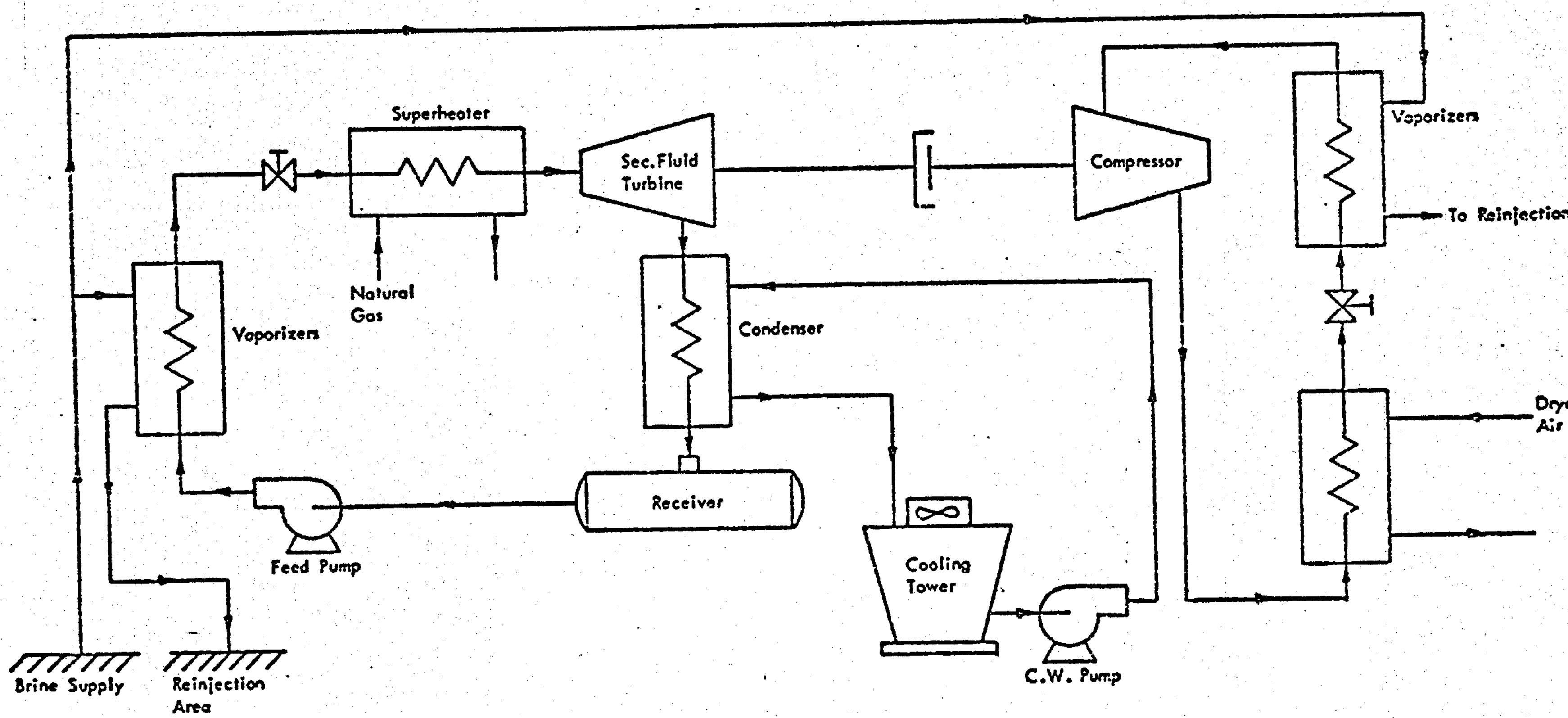

Figure 3. Geothermal augmentation with heat pump, isobutane turbine and heat pump circuits.

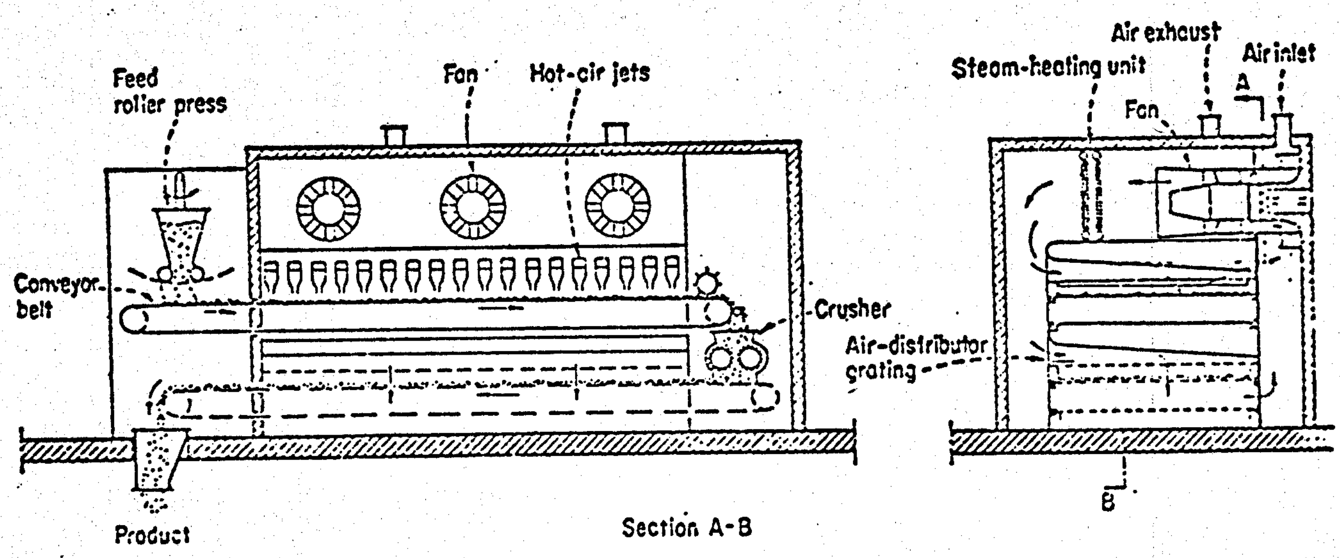

Figure 4. The Folmer alfalfa dryer.

plant if a significant savings per Gigajoule with the larger pipeline could be realized. For these cases pipeline length is approximately 4 kilometers. Another option would be to shift the entire plant south toward the town of Heber along the railroad to a point nearer the center of well drilling activity. A pipeline from well-head to plant might be little more than 1.5 kilometers long in this case.

Analysis of Other Dried Crops and Crop Data Base Construction

Our rather discouraging findings for the application of geothermal energy to alfalfa dehydration have prompted us to turn to the analysis of other crop processing applications in order to discover which might have favorable locations with respect to geothermal energy, and more favorable institutional and marketing situations. A primary tool for this analysis will be bar charts that depict for the eleven continental geothermal states the harvested area, units produced, and dollar value of the dryable crops listed in Table III. These commodities appear to offer a high potential for the commercial application of geothermal heat for drying and dehydrating. They are currently processed (with the exception of chicken manure) in significant amounts in the United States with methods for which the use of geothermal heat between 90 and 150°C may be technically feasible.

Before turning to our preliminary bar charts, the methods used to compile the crop data on which they are based will be described. Our first task was to generate a list of counties, the administrative unit into which U.S. states are divided, for which geothermal heat at temperatures above 90°C could be made available for drying agricultural commodities. Secondly, the list of those commodities which are now dried, including alfalfa, was prepared. Finally, agricultural data relating to the harvested crop area, units of production, and crop value for each of these commodities was acquired for the counties identified in the first task. The output, thought by the study team to be unique for the United States, is a comprehensive data base showing the coincidence of 22 crops with identified geothermal resources.

The hydrothermal convection systems identified by Renner, White, and Williams in U.S.G.S. Circular 726, Assessment of Geothermal Resources of the United States--1975, form the primary geothermal resource data base. While emphasis is placed on those systems with estimated temperatures between 90 and 150°C, it was thought unwise at this time to eliminate those estimated to be hotter in case plans to use these for electrical power generation do not materialize in some locations.

The township, range, and section locations of all Circular 726 resources, excluding those in national parks, were found on 1:500,000-scale state "Geothermal Land Classification Maps" (prepared by the U.S.G.S. Western Region Conservation Division, Office of the Area Geologist). A scale 80-km circle was drawn, centered on the geothermal resource (Figure 5 shows the Arizona example). Eighty kilometers was estimated to be the maximum sum of (a) the distance to which geothermal hot water could be transported economically to a dehydration plant; and (b) the distance from which alfalfa could be transported economically to such a plant. Once circles for each resource in each state were drawn, the areas so circumscribed were aggregated into two groups:

Table III

COMMODITIES WITH HIGH POTENTIAL FOR GEOTHERMAL DRYING

GRAINS & GRASSES	VEGETABLES	FRUITS	LIVESTOCK PRODUCTS
corn alfalfa (hay) rice peanuts seed cotton flax seed sorghum dried brewer's grain (barley)	potatoes onions garlic chili peppers carrots celery sweet potatoes (drying & healing) tomatoes (drying & concentrate)	prunes apples apricots peaches pears grapes (raisins)	milk (drying & pasteurizing) whey eggs chicken manure (potential protein supplement in feeds)

the total area defined by 90 to 150°C resources and the total area defined by 150°C-plus resources. The intersection of each county's area (see Figure 6) with each of these two areas was plotted and measured with a planimeter. In addition, the two statewide, resource-defined areas were combined to yield a third, the total area within 80 kilometers of all U.S.G.S.-identified resources. Finally, the intersection of each county with this third area for each state was measured (see Figure 7).

Two hundred and seventy-five counties in 11 states in and west of the Rocky Mountains were enumerated. In Arizona, California, Colorado, Idaho, Nevada, and Utah over 75 percent of each state's counties were included. In New Mexico, Oregon, and Washington, 50 to 75 percent were included. In Montana and Wyoming, less than half were included.

Crop area and production data for each of the 22 crops in each of the 275 counties was extracted from the 1969 Census of Agriculture* and put on computer files. (1969 appears to be the most recent year for which such figures are available on a national basis.) Crop values were based on the prices received by farmers, and were calculated by one of several BASIC computer codes.

Another code calculated the percent of each county area that is within 80 kilometers of the identified geothermal resources. These percentages were used to weight the crop statistics in order to allow estimates to be made of harvested crop areas, production and values within sub-county regions like those shown for Arizona in Figure 7. (These sub-county estimates are based on the assumption that each crop is distributed homogeneously throughout each county because no simple method of locating crops within the counties was devised.) The county crop data may be used without weighting in order to evaluate them for entire counties.

Our initial use of this crop data base has been to prepare summations of the crop areas and values for each state to be used in selecting dryable crops for further analysis. These state summations were in turn added for each crop separately to produce the bar graphs shown in Figures 8 and 9. Alfalfa and barley are clearly the most common of the 22 dryable crops grown near identified geothermal resources, but additional crops--cotton, Irish potatoes, tomatoes, and grapes--are among the most valuable. A third set of bar graphs will show the estimated energy now used for drying each crop in each of the 11 states. It is this energy data that will provide the primary tool for selection of other crops for further study of geothermal drying applications.

Similar data for the 10 most valuable crops in each of the 11 states regardless of whether the crops are dried, have also been gathered. This data will also be accessible by county or sub-county region and will permit the data base to be used in a variety of ways by others. It might be used

---

*U.S. Bureau of the Census, Census of Agriculture, 1969: Volume I, Area Reports (Washington, D.C.: U.S. Government Printing Office, May 1972).

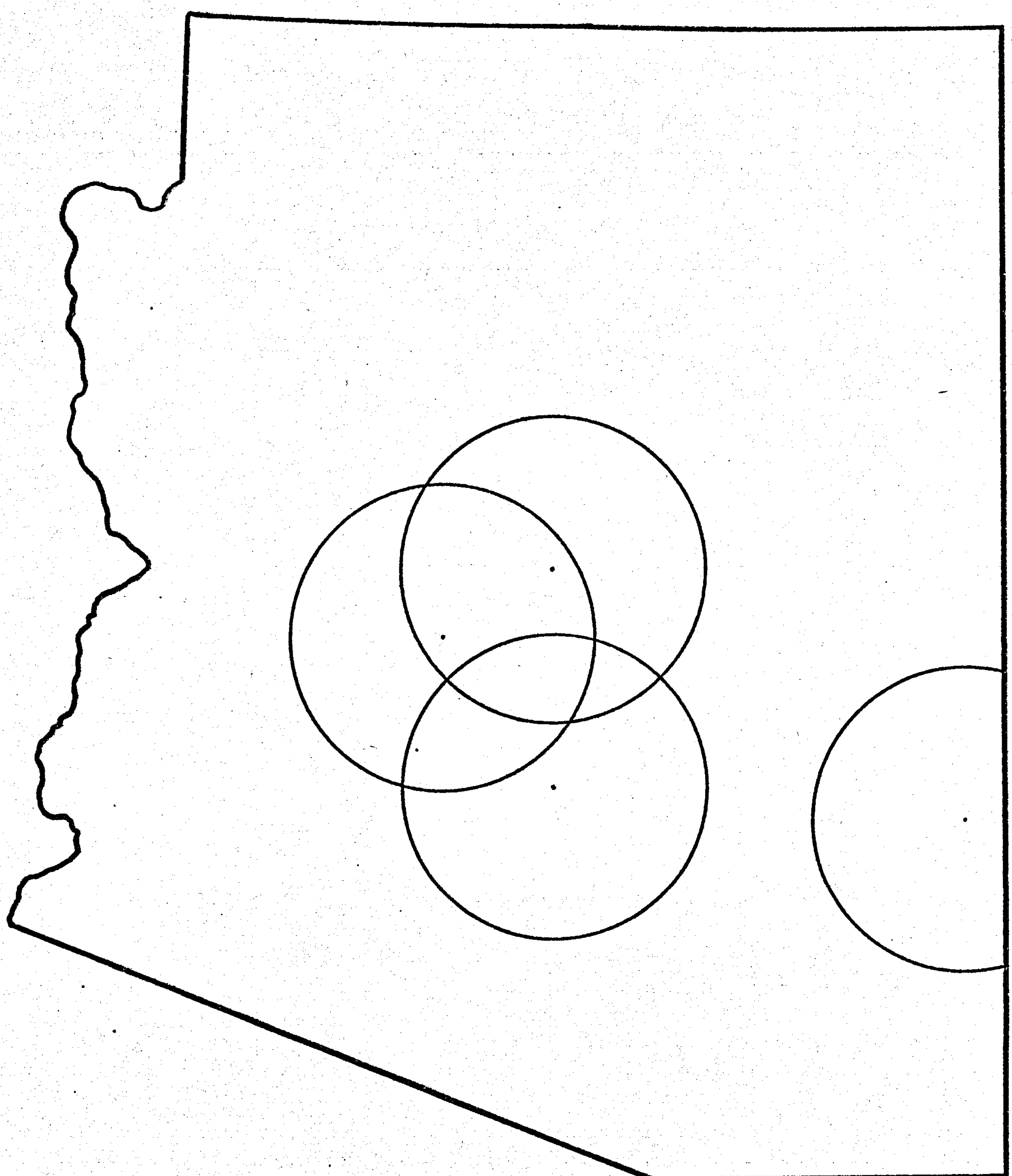

Figure 5. Arizona: Hydrothermal Resources

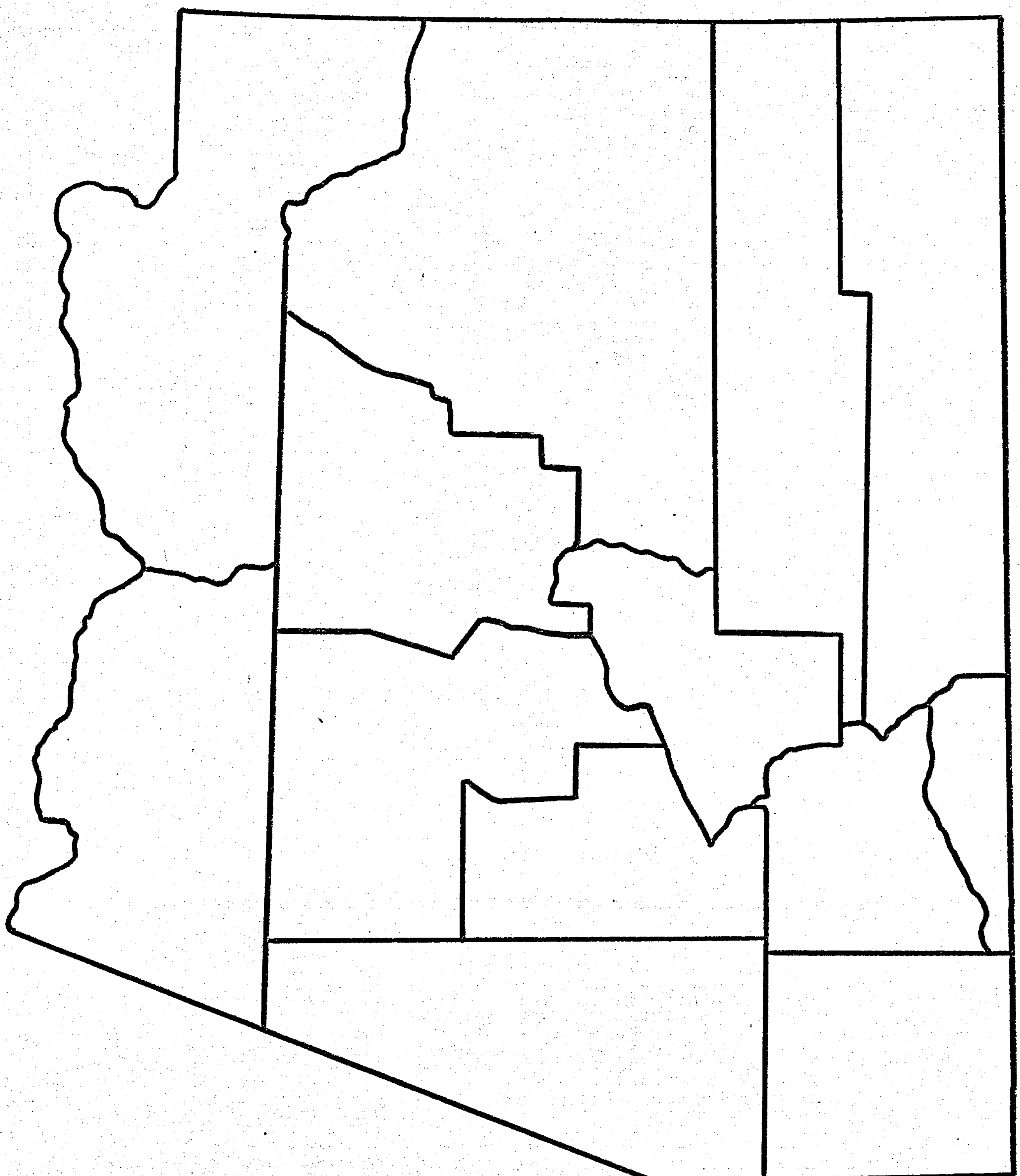

Figure 6. Arizona: County Boundaries.

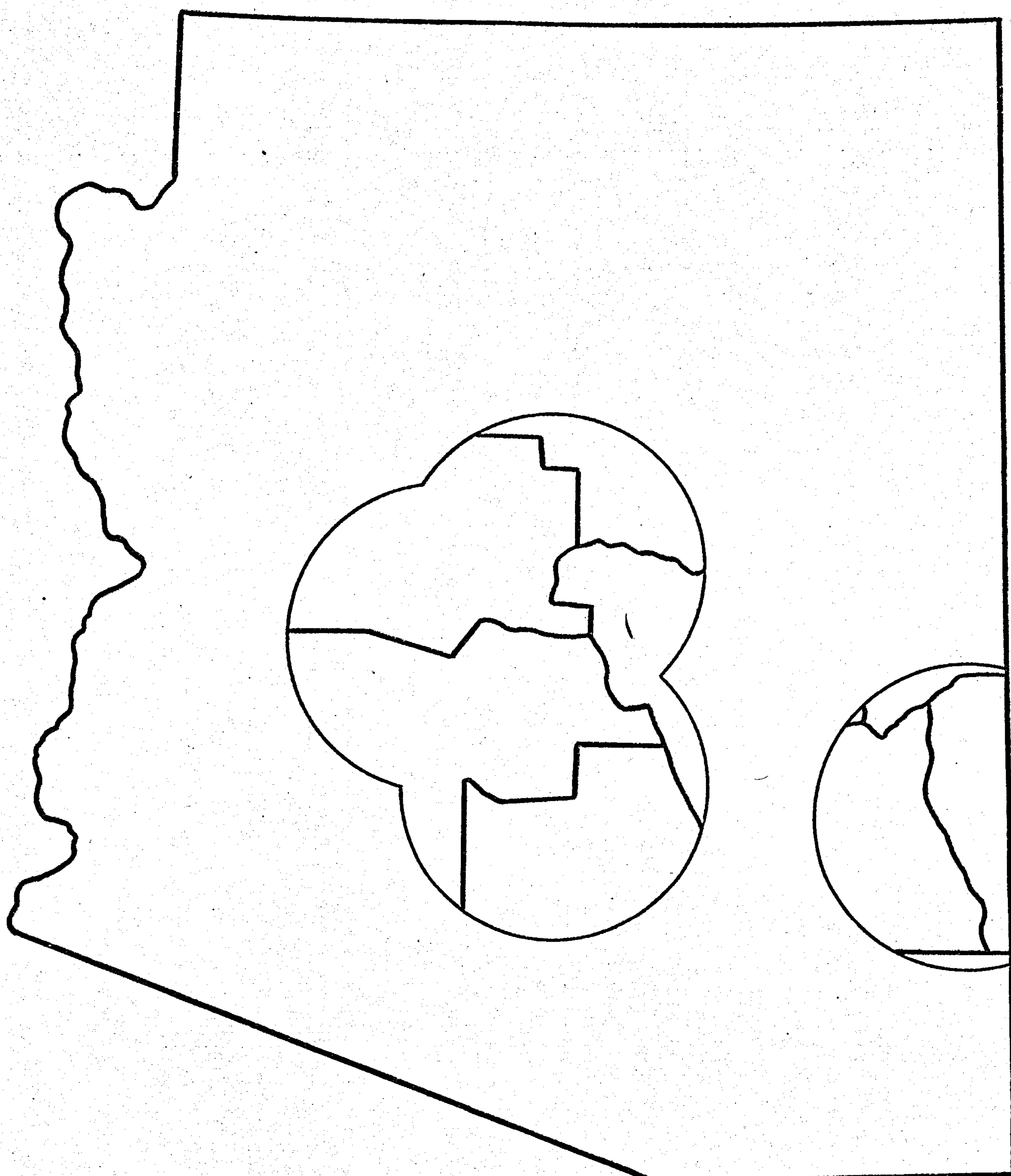

Figure 7. Arizona: Sub-county areas within 80
kilometers of hydrothermal resources.

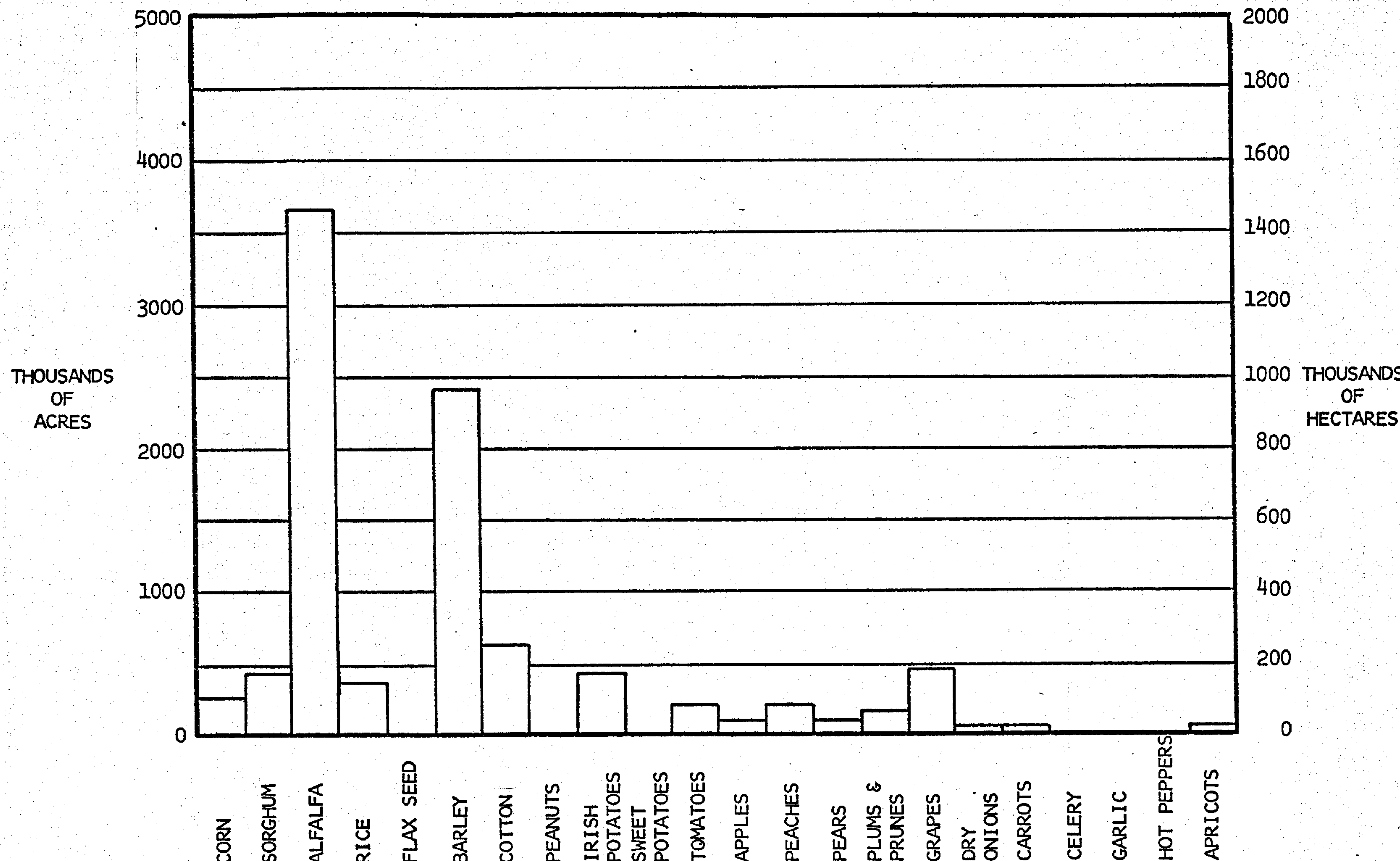

Figure 8. 1969 continental U.S. crop areas near identified hydrothermal systems greater than 90°C.

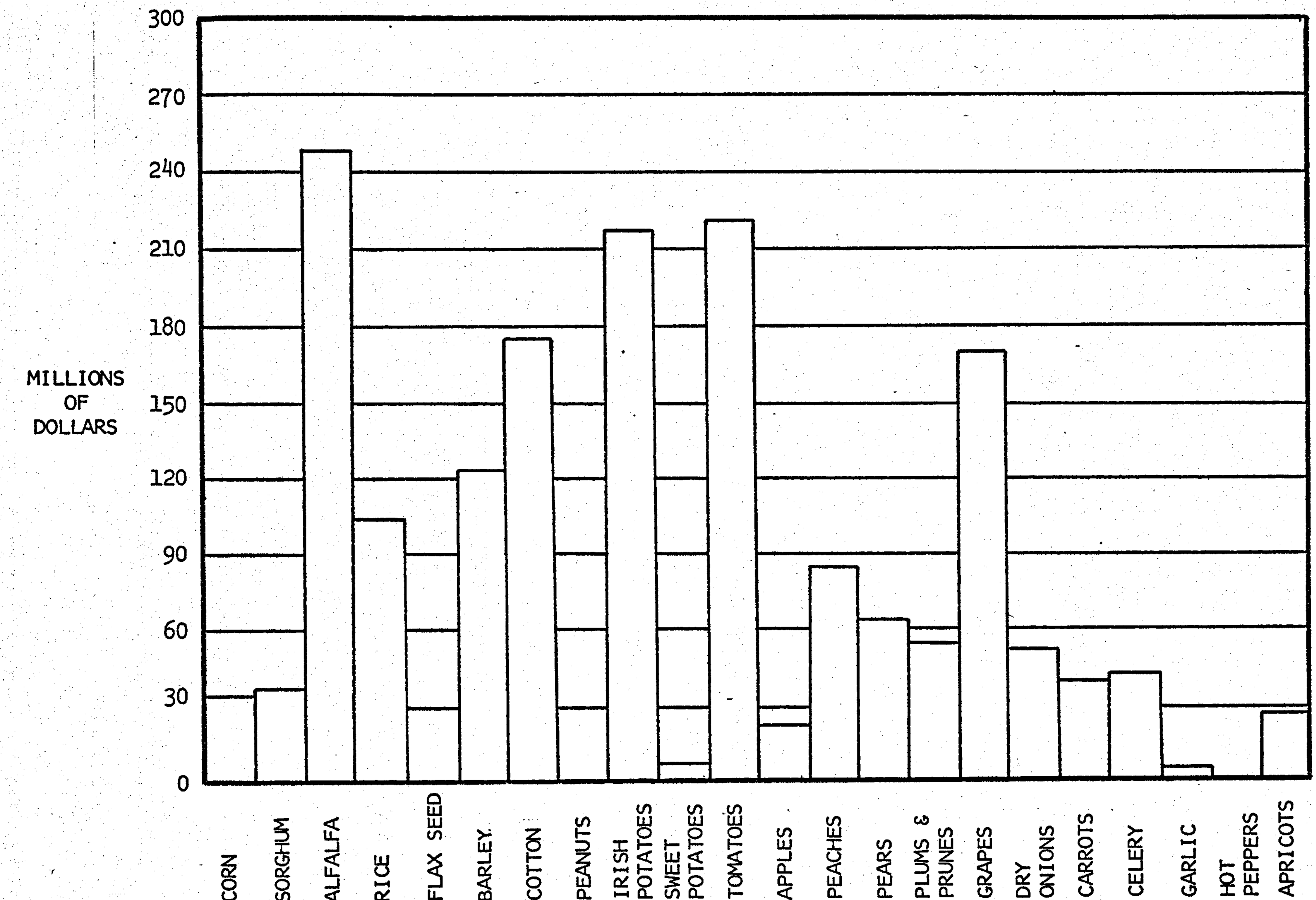

Figure 9. 1969 continental U.S. crop values in areas near identified hydrothermal systems with estimated subsurface temperatures greater than 90°C.

to evaluate the irrigation potential of geothermal water for existing crops in a state or region. Work at Idaho National Engineering Lab* has indicated that wheat, barley, oats, grasses, alfalfa, potatoes, and garden vegetables can be grown successfully with flood or sprinkler application of geothermal water in the Raft River Valley of Idaho. The data base might also permit an evaluation to be made of the potential air and water pollution impacts on crop production due to geothermal power plant emissions or surface effluent disposal.

Other Crop Processing Applications Under Study

In addition to our study of the established dehydration process for alfalfa, we have been investigating a "state of the art" alternative for which geothermal energy might be used. Because of the potential improvements in product quality, marketability, and energy savings, wet processing (or mechanical de-watering) of alfalfa is currently an active research area. Much of the research in the U.S. centers around the production of a high protein, high xanthophyll juice coagulant termed "Pro-Xan" which is better suited to poultry production than conventional dehy pellets. A high quality protein for human consumption also can be produced and has been shown to be effective in the treatment of protein deficiency disease. Partial de-watering of raw alfalfa permits a reduction in the heat requirement for complete dehydration. Also, the juice fraction is processed at a relatively low temperature, about 85°C. Both of these factors lead us to believe that low temperature geothermal heat could be included in the wet fractionation procedure to produce an important vegetable protein.

The crop residues and spoilage left in the field after harvesting constitute an important potential source of animal feed ingredients. Geothermal heat might be used in digestibility enhancing processes for woody materials such as wheat stems. Automated harvesting machinery spoils part of lettuce and other green crop yields. This spoilage might be dehydrated geothermally for feed use.

Summary

Alfalfa dehydration was chosen for intensive study of the potential application of geothermal energy because alfalfa is widespread in states with identified geothermal resources, the process is energy intensive, and the industry is threatened by natural gas shortages. The conventional dehydration process is performed within 20 kilometers of the alfalfa supply in most cases. An initial air temperature from 500 to 1000°C is used, much too high for direct substitution of geothermal energy and use of present dryers. The most suitable and least expensive dryer for geothermal use appears to be a conveyor type similar to that used to dry alfalfa with moderate-temperature geothermal heat in the Broadlands area, New Zealand.

---

*R.C. Schmitt and S.G. Spencer, "Beneficial Uses of Geothermal Energy: Description and Preliminary Results for Phase 1 of the Raft River Irrigation Experiment," EG&G, Inc., Report TREE-1048 (January 1977). Available NTIS.

An economic study of pipeline transmission of geothermal water to dehydrating plants showed that it is probably not feasible to locate plants more than a few kilometers from the wellhead. An institutional study of the U.S. alfalfa dehydration industry revealed only three operating plants within 20 kilometers of identified geothermal sources. Declining national production of dehydrated alfalfa suggests that construction of new plants is not likely.

The largest of the three operating dehy plants near identified geothermal sources is located in El Centro, California within the Heber Known Geothermal Resource Area. The operator is optimistic about his market and will be enthusiastic about geothermal retrofitting if energy cost is no more than about 50 percent of his present natural gas cost and capital investment requirements are not excessive. The preliminary estimate for geothermal heat exchanger and conveyor dryers for this plant is $1.6 million. Energy cost at the heat exchanger inlet is to be estimated with the GEOCOST model.

Other crops that are now routinely dried are to be evaluated briefly for the potential application of geothermal heat. A data base of agricultural statistics for counties near all U.S.G.S.-identified hydrothermal resources was assembled to aid in this task. The crops with the largest harvested areas (acres or hectares) are alfalfa and barley; the most valuable crops include alfalfa, barley, cotton, potatoes, tomatoes and grapes. The crop data base might also be used by others who wish to evaluate geothermal water irrigation or pollution hazards, for example.

In addition to conventional dehydration processes, we are also studying an improved alfalfa product called Pro-Xan and harvest waste processing for possible geothermal application.