IDO/1628-4

THE USE OF GEOTHERMAL HEAT FOR CROP DRYING AND RELATED AGRICULTURAL APPLICATIONS

FINAL REPORT

THEODORE J. GORDON   THOMAS C. WRIGHT
ELIHU FEIN
THOMAS R. MUNSON   ROBERT C. RICHMOND

THE FUTURES GROUP
124 Hebron Ave., Glastonbury, Connecticut 06033

IDAHO OPERATIONS OFFICE

IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

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Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price: Printed Copy $10.75; Microfiche $3.00

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Distribution Category:
UC-66g

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Theodore J. Gordon
Thomas C. Wright
Elihu Fein
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Robert C. Richmond

March 1978

Prepared for
The Department of Energy
(Formerly the Energy Research and Development Administration)
Division of Geothermal Energy
Under Contract E(10-1)-1628

PREFACE

This document contains a report on the work done by The Futures Group and its subcontractor, Midwest Research Institute, to investigate the use of low-quality geothermal heat in the drying of agricultural products, particularly alfalfa. The work was sponsored under contract to the Energy Research and Development Administration (E(10-1)-1628) and extended from October 4, 1976 to November 10, 1977.

The principal investigator for the study was Theodore J. Gordon who provided project management and direction. Rod Athey, Jerry Bradley, and Dennis Costello served as principal investigators for the Midwest Research Institute portion of the study; Mr. James Galeski prepared the geothermal alfalfa dryer designs. On The Futures Group staff, Mr. Thomas Wright performed the research associated with the geographic coincidence between geothermal resources and agricultural products, developed the concept of "multi-crop drying centers," and coordinated the major portion of the technical work. Mr. Thomas Munson constructed the thermodynamic computer model used to determine the rate of drying in a rotary dryer and analyzed thermodynamic and engineering considerations involved in particular installations. Mr. Eli Fein was responsible for studying institutional aspects of the use of low-quality geothermal fluids in agricultural drying applications. Mr. Robert Richmond contributed work in the study of biological processes associated with storing and drying of alfalfa.

Two consultants also worked with the study team. Professor Stanley Seaver of the University of Connecticut (agricultural economics) made suggestions about study scope and direction early in the research. Professor Herbert Klei of the University of Connecticut (chemical engineering) made very significant contributions in estimating the cost associated with the transmission of low-quality geothermal fluids.

Finally, the study team is indebted to Mr. Steve Metzger who served as the ERDA program manager. Mr. Metzger met with the study team at several points throughout this work and contributed valuable suggestions and guidance.

ACKNOWLEDGMENTS

The study team would like to acknowledge especially the assistance of the following individuals:

- Dr. Clarence H. Bloomster, Ms. Linda L. Fassbender, and Mr. Craig McDonald of the Economic Analysis Section, Battelle Pacific Northwest Laboratories, Richland, Washington.

- Mr. Albert M. Cooper, Chevron Resources Company, San Francisco, California.

- Messrs. Wally Heard and Frank Wheeler, United Alfalfa Mills, El Centro, California.

- Mr. Willard E. Johnson, WESTEC Services, Inc., San Diego, California.

- Dr. Paul J. Lienau and Mr. Don J. Karr, Geoheat Utilization Center, Oregon Institute of Technology, Klamath Falls, Oregon.

- Dr. Lyle A. Livingston, Project Leader, Dr. George O. Kohler, Chief of Operations, and Mr. Benny Knuckles, Research Chemist, U.S. Department of Agriculture Western Regional Research Laboratory, Berkeley, California.

- Mr. Fletcher C. Paddison, Assistant Director, Advanced Research Programs, The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland.

- Mr. Leo Pedersen, Doctoral Student, University of California, Davis.

- Mr. D. N. Perrit, Director, Broadlands Lucerne Company Ltd., Rotorua, New Zealand.

- Mr. Ken Pirie, Industrial Division Manager, Fisher & Paykel Engineering Ltd., Auckland, New Zealand.

- Mr. Kenneth D. Smith, Executive Vice President, Mr. William L. Arnold, Director of Marketing, American Dehydrators Association, Mission, Kansas.

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ABSTRACT

At least 2 x 10^{13} Btu's are used each year for crop drying within 50 miles of identified hydrothermal resources. Alfalfa dehydration consumes a substantial portion of this energy, 1.4 x 10^{12} Btu's. In addition, the coincidence between alfalfa-growing areas in the western United States and geothermal resources is relatively large: about 1 million acres in the top 25 alfalfa-producing counties of those that are partly or wholly within 50 miles of resources. These observations led to selection of the alfalfa dehydration industry for in-depth analysis of the application of moderate-temperature geothermal heat.

Six geothermal heat exchanger/dryer configurations were examined. A low-temperature conveyor dryer using geothermal water to supply all required heat was chosen for site-specific analysis, the retrofitting of a large alfalfa dehydration plant within the Heber KGRA in the Imperial Valley, California. Even in the most favorable scenario--sharing a geothermal pipeline with the neighboring fertilizer plant--geothermal retrofitting would increase the price of the alfalfa "dehy" about 40 percent. The geothermal brine is estimated to cost $2.58/million Btu's compared with a 1977 natural gas cost of $1.15. Capital cost for heat exchangers and the new dryers is estimated at $3.3 million.

The Heber plant appeared to offer the only good opportunity for geothermal retrofitting of an existing alfalfa dehydration plant. Construction of new plants at geothermal resource sites cannot be justified due to the uncertain state of the dehy industry. Increased solar drying of alfalfa is the recommended method for saving energy.

Use of geothermal heat for drying other crops may be much more promising. The potato dehydration industry, which is concentrated in the geothermal-rich Snake River Valley of Idaho, appears to offer good potential for geothermal retrofitting; about 4.7 x 10^{12} Btu's are used annually by plants within 50 miles of resources. Drying together at the geothermal wellhead several crops that have interlocking processing seasons and drying-temperature requirements may be quite attractive. The best "multicrop drying center" site identified was at Power Ranch Wells, Arizona; 34 other sites were defined.

Agricultural processing applications other than drying were investigated briefly. Extraction of leaf-protein from alfalfa could provide an important new source of human and animal food; moderate-temperature geothermal heat could be used. Good coincidence between geothermal resources and areas that produce large amounts of crop residues was found; these residues could be processed for animal feed.

CHAPTER 1: INTRODUCTION AND SUMMARY

The most important use for geothermal energy is probably the generation of electricity. The production of electricity from geothermal sources currently depends, however, on the use of vapor-dominated or high-quality liquid-dominated resources.

Vapor-dominated resources are those which are primarily single phase, thermodynamically saturated, superheated steam. The number of vapor-dominated sites discovered to date are quite limited and include The Geysers, California; Larderello, Italy; Matsukawa, Japan; Onikobe, Japan; and the Monte Amiata Regions, Italy. High-quality liquid-dominated resources are two-phase mixtures of liquid water (or brine) and steam at an elevated temperature and corresponding saturation pressure. Liquid-dominated resources are much more abundant than vapor-dominated, and lower temperature liquid-dominated resources are more abundant than higher temperature.[1,2,4]

Studies have shown that the amount of low-quality liquid-dominated resources (50-150°C) is probably very large, but its extent is as yet uncertain.[1,3] The use of these resources in the generation of electricity is likely to be impractical for the next several decades at least, yet these resources might find important nonelectric uses including space heating and air conditioning; the production of desalinated water; mineral extraction; and process heat.[4] In areas where geothermal resources exist in proximity to population centers, they have been used successfully for space heating and air conditioning. Large-scale use of geothermal energy is currently being made for this purpose in Iceland, Hungary, the USSR, New Zealand, Japan, and the United States. Desalinated water can be produced from geothermal sources through multiple-effect distillation or multi-stage flashing. Geothermal resources provide a great potential supply of desalted water.[5] The U.S. Department of the Interior is currently operating a geothermal desalination plant in the Imperial Valley of California.[6] As for mineral extraction, methods for producing potassium, lithium, and calcium have been described; geothermal brines contain large amounts of such minerals which may be recovered by precipitation.[7]

Geothermal energy currently provides process heat for industry and agriculture in a number of countries.[8] Among the industrial uses of geothermal heat are: drying, distillation, refrigeration, deicing, tempering in mining operations, production of alumina from bauxite, production of heavy water through hydrogen sulfide water isotope-exchange processes, and other applications in which hot water or steam is used.[9]

Applications of low-quality geothermal resources to agriculture have also been made. These applications include: drying of farm products, canning of food, evaporation of sugar in refining, extraction of salts by evaporation and crystallization, fresh water by distillation, drying of organic materials--

seaweeds, grass, vegetables, etc.--drying of stock fish, space heating of greenhouses, animal husbandry, soil sterilization, soil warming, biodegradation, enhancement of fermentation processes, hatching of fish, and aquaculture in general.[10]

The Futures Group and its subcontractor, Midwest Research Institute, under contract to the Division of Geothermal Energy, U.S. Energy Research and Development Administration, performed a study of the application of moderate temperature geothermal heat (90-150°C) to commercial drying of grasses, grains, and selected fruits, vegetables, and livestock products.[11] The study extended from October 1976 to October 1977.

Study Objectives

The focus of the work was on alfalfa dehydration 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 million Btu's per ton 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 15 trillion Btu's of natural gas. Finally, the alfalfa dehydration industry has suffered curtailment of natural gas deliveries in some locations. 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.

More specifically, the objectives of this study included

- evaluating the economics of the use of moderate temperature geothermal heat in alfalfa drying, comparing the geothermal resource with other sources of heat from the standpoint of the user and supplier of the resource.

- evaluating these uses from the standpoint of the alfalfa-drying industry and the public, including analyses of the economics of the use of geothermal resources in this application and energy savings to be achieved through the use of geothermal heat.

- extending this analysis to include the application of geothermal heat to other agricultural drying processes.

- identifying key impacts which would flow from implementation of these uses within the applicable geographic regions, not only for the businesses employing them, but for other interest groups as well.

- identifying policies which would seem to be effective in encouraging the use of geothermal heat in applications identified as appropriate.

The Conventional Alfalfa Dehydration Process

Before describing the steps followed in this study, it may be useful to review the standard process used to produce dehydrated alfalfa meal, which is 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 10 to 15 miles 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 900-1800°F depending upon the moisture content of the material to be dehydrated (1200°F 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 60 feet, 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 250°F 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 United States 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 dryers most commonly produce about 3 dry tons 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 tons 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 ton were quoted during interviews with western dehydrators. These costs represent 10 to 20 percent of the finished product price.

Study Design

The steps involved in our study included:

First: The list of counties was formed that were partly or wholly within 50 miles of identified geothermal resources in 11 western states. This list contained 275 counties, and for these counties, crop statistics were compiled. The statistics included crop acreage, production, and drying energy consumption for each of approximately 20 crops in order to evaluate how significant agricultural drying with geothermal heat might be in particular states. This information appears in Chapters 4 and 10 of this report.

Second: Studies were made of design and costs of systems to deliver geothermal hot water from geothermal sites to dehydration plants. Two specific analyses were conducted: the first involved the parametric analysis of piping costs for three different plant loads, and the second utilized the GEOCOST fluid transmission submodel developed at Battelle Pacific Northwest Laboratories. For the parametric analysis, an alfalfa dehydration plant requiring 15 million Btu's/hr to produce 3 tons/hr of dried alfalfa was assumed as a base case; heat demands of 50 and 100 million Btu's/hr were also considered in order to assess the effect of scale on costs. This work is summarized in Chapter 5.

Third: Preliminary designs of alfalfa dryers were considered. The first involved geothermal "augmentation"; here the drying air is preheated geothermally and then raised to the conventional rotary drum temperature of 500-1000°C (1000-1800°F) by natural gas combustion. The second method uses a different type of dryer with an air temperature of about 140°C (280°F) in a manner that permits the drying to occur at these lower temperatures. Finally, heat pumps were considered to raise the temperature from the geothermal fluids enough to provide high-temperature inlet air to a conventional drum dryer. In all, six configurations were considered in some detail. This work is reported in Chapter 6.

Fourth: In order to reach a better understanding of the dynamics of the alfalfa-drying process, a computer simulation of rotary-drum dehydrators was constructed to examine the range of design and operating parameters that would be required to use geothermal sources in the dehydration process. The program was based on an analysis performed by Air Resources, Inc. for the American Dehydrators Association in 1975. An essentially new computer code was developed and the present program can consider either single- or triple-pass dehydrators and can be used for the analysis of both gas-fired or heat-exchanger supply systems. This work is described in Chapter 7.

Fifth: The nutrient quality and market value of low-temperature-dried alfalfa was considered. This work was performed to determine whether alfalfa can be dried with air heated by 150°C or less geothermal water to yield a nutritious and marketable product. This work involved identifying changes in nutritional quality of alfalfa when the material is dried under various conditions of time, temperature, and initial moisture. A great help in this analysis was information obtained from the single low-temperature geothermal alfalfa-drying plant operating in the world, in the Broadlands, New Zealand. Chapter 8 describes this work.

Sixth: An analysis was made of the alfalfa dehydrating industry to determine whether or not it has the capacity to absorb drying equipment based on the use of geothermal energy. This analysis is contained in Chapter 3 of this report.

Seventh: A site-specific analysis of geothermal alfalfa dehydration was made. This specific site considered is an active dehydration operation near El Centro, California in the Imperial Valley, California near the Heber Known Geothermal Resource Area. The dehydration plant is across the road from the Valley Nitrogen Plant, a fertilizer manufacturer, and the subject of a site-specific nonelectric study being performed under contract to the U.S. Energy Research and Development Administration. Three miles south of the dehydration plant is the center of the Heber anomaly with its concentration of geothermal wells. The plant considered produces about 10 tons per hour of dehydrated alfalfa. We attempted to answer: what would it cost for this particular operator to convert to geothermal heat? This work is reported in Chapter 9 of this report.

Eighth: Crops other than alfalfa were considered. As in the case of alfalfa we first considered their distance from geothermal energy sources and prepared a listing of crop area and production data for each of 36 crops in the 275 counties considered. The most valuable crops near resources are Irish potatoes, tomatoes, lettuce and sugar beets. The concept of multicrop drying centers (MDCs) was investigated, utilizing this data and information about the drying processes and seasons for 12 of the crops. This concept is discussed in Chapter 10.

Ninth: The study team considered wet processing (or mechanical dewatering) of alfalfa. Much of the research of the United States centers around the production of a high-protein, high-xanthophyll juice coagulant called "Pro-Xan" which is better suited to poultry production than conventional dehy pellets. Partial dewatering 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. Finally, we considered the possibilities for use of geothermal heat in processes used to improve the digestibility of crop residues and spoilage for woody materials such as wheat stems for use in production of animal-feed ingredients. Typically, these processes can be performed at low temperatures. These alternative uses of geothermal heat in agriculture are reported in Chapter 11.

Tenth: Considering all of the previous work, policy implications were studied. Policies were related to the modification of existing drying systems, the introduction of new drying systems well suited to geothermal energy sources, and other techniques. The policy analysis considered alfalfa, other crops, and combinations of alfalfa and other crops. In each instance, policies were judged on the basis of the cost of the energy delivered to the drying process, the amount of natural gas saved, the marginal cost required, the total investment required, the acceptability of the policy to the industries involved, nutritional impact, and probable date of implementation. Modes of introduction included: demonstration plants, stimulation of market, subsidy, increasing the cost of competing energy sources, and regulation. This analysis appears in Chapter 12.

The next chapter summarizes the principal findings and recommendations of the study.

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CHAPTER 2: STUDY FINDINGS AND RECOMMENDATIONS

Findings

We found, principally, that it does not appear cost-effective to modify current alfalfa-dehydrating operations on a large scale or to construct new plants for drying alfalfa using low-grade geothermal energy. We reached these conclusions because

- there are few alfalfa drying plants in existence that are candidates for conversion.

- the conversion is relatively costly and would add to the price of dehydrated alfalfa (dehy) an amount that would not permit it to compete with other sources of animal-feed protein.

- the construction of new plants (rather than retrofit of existing plants) cannot be justified on the basis of our economic and industrial evaluations.

- even if the use of geothermal energy were encouraged through the use of artificial subsidies, grants, or other policy mechanisms, the amount of natural gas to be saved is relatively low.

- curtailments of natural gas supply would be very damaging to the existing dehy industry. However, if large-scale curtailments were to occur, geothermal energy would not be a good substitute since less expensive and less energy-intensive alternatives to dehy are probably available for most uses.

The dehy industry utilizes about 15×10^9 SCF of natural gas annually; 1.4×10^9 SCF are utilized by dehydrators within 50 miles of identified geothermal resources.

The primary market for dehy in the West is the poultry-feed industry; the xanthophyll component in the dehy serves as a yellowing agent for egg yolks and broiler skins. Substitutes are available for this application--for example, marigold petals can serve as a xanthophyll source in poultry feed. Not all of the beneficial nutrient qualities of dehy are known with certainty; however, a rather small price increase would make it less cost-effective than competing feed ingredients.

If natural gas were severely curtailed for one reason or another, we would expect to see an increase in the production of sun-cured alfalfa for ruminant feed and the substitution of other xanthophyll sources in poultry feed. The national impact of such a substitution would not be large; the impact on the dehy industry itself would be significant.

In considering alternative strategies that might be followed by the government, we found that modifications to existing alfalfa-drying systems would cost the least, both in terms of required investment and operating costs, and save the most natural gas.

Of all the strategies considered, field wilting followed by conventional drying may be the best bet. Careful control could result in minimum loss of nutritional qualities and, assuming that harvesting could be properly timed, quite appreciable quantities of gas could be saved. Furthermore, this technique could be practiced throughout the country, not just in the West. If all dehy in the United States were processed this way, approximately 6×10^9 SCF of natural gas could be saved. The dehy industry would not be affected greatly and the product would remain usable in its present applications.

A site-specific analysis of geothermal retrofitting was made for a very promising alfalfa dehydration plant at El Centro, California. It showed that even in the most favorable scenario, use of geothermal energy would add about $40 per ton to the price of the dehy product, or about a 40-percent increase in the present price.

This scenario involved the use of a shared geothermal pipeline from the Heber KGRA by the Valley Nitrogen Plant and United Alfalfa Mills. Chevron Resources Company, the geothermal leaseholder, would charge about $2.60 per million Btu's to deliver the energy to the two plants; present natural gas price is about $1.15 per million Btu's. In addition to the brine price, however, a capital investment of about $3 million in new low-temperature dryers and geothermal-to-air heat exchangers would be needed in this scenario in order to completely replace natural gas. The cost of capital recovery amounts to about 30 percent of the total additional energy cost that geothermal energy use would require. Substantial added costs for electricity, heat-exchanger and dryer maintenance, and general and administrative expenses are also projected.

The operator of the El Centro dehydration plant feels that the price increase projected under the 100-percent geothermal-use scenario would be prohibitive at present. He also indicated that the less-ambitious scenarios, which would replace only a portion of the present natural gas use, would not solve his problem--gas curtailment. His most likely course would be to switch to sun-cured alfalfa were curtailments to occur.

In the course of our research we found that processes were being developed for the extraction of leaf protein from alfalfa that could provide an important new source of human and animal food. In view of world population growth and the probable need for new food sources within the next few decades, such processes may have enormous importance in the short term. On a per-acre basis, no plant or animal exceeds alfalfa in terms of protein production per unit of harvested land area. Therefore, we probed to some depth the state-of-the-art of the new, experimental protein-extraction processes. We found that these processes require heat and that low-temperature geothermal resources could supply the required energy at the appropriate temperatures and heat-flow rates for reasonably sized plants.

The study team also investigated the use of geothermal energy for drying crops other than alfalfa. Some of these applications, in contrast to alfalfa, seem quite promising. In particular, potato dehydration to produce granules, flakes, slices, dices, and starch appears to have few of the impediments associated with the use of geothermal energy in alfalfa dehydration. The market for dehydrated potato products is growing. The maximum temperature required in any potato-drying process is about 340°F (for flakes) and thus can be provided by geothermal fluids without augmentation from other energy sources. Furthermore, potato-dehydration plants currently coincide in many instances with existing geothermal resource locations. (For example, at least 15 potato drying plants are located in the Snake River Valley of Idaho; only two of these plants are more than 50 miles from identified geothermal resources.) Using estimates for installing and operating geothermally-powered dryers for potato dehydration, we find that the product would increase in cost less than one cent per pound. The cost of geothermal heat is low because a potato-dehydration plant can be operated almost year-round, resulting in high utilization of the geothermal system.

We found synergies among the drying and processing requirements of several crops. The synergies result from "dove-tailing" of the crop processing seasons and/or compatible temperature cascading (the output temperature of one process serving as the input temperature of the next). Combinations involving potatoes and onions appear to be particularly attractive. The most promising site for a multicrop drying center appears to be at Power Ranch Wells in Maricopa County, Arizona. This site is followed in potential by those at the Brawley KGRA in the Imperial Valley, California, and Napa Soda (Rock, Priest) Spring near the Geysers in Northern California.

Recommendations

1. Since the cost of using low-quality geothermal fluids depends greatly on well, distribution, and heat-exchanger costs, DOE should emphasize research into very low cost wells, distribution systems, and heat-exchange systems. These elements will be key to any direct-heat application of low- or moderate-temperature geothermal fluids.

2. DOE should study and design incentives for encouraging the field wilting of alfalfa in conjunction with conventional alfalfa dehydration; the use of sun-cured alfalfa as a replacement for conventionally dried alfalfa should also be investigated carefully. Both techniques could save appreciable amounts of natural gas; the former would have minimum impact on the

dehydration industry. One incentive that might be necessary in order to adopt either of these approaches is some form of guarantee that would guard the farmer against loss of his crop in the event of unexpected adverse weather during the field-wilting or sun-curing process.

3. In view of the promising initial findings with respect to the use of geothermal energy for potato dehydration, we recommend that a study of the sort performed here for alfalfa be performed for the potato-processing industry. We are relatively certain that the economics of drying as studied here for alfalfa will apply to potato dehydration; therefore, the recommended study should be of short duration and, if it proves encouraging, should be followed quickly by a demonstration plant.

4. The notion of synergy among agricultural processes that require heat should be pursued. We have identified here several crops that seem to "fit together" very well. As a particular recommendation, we suggest that DOE consider convening a conference of the various drying industries to acquaint them with the potential use of geothermal fluids in drying processes. This study could serve as a starting point for such a conference. A number of joint projects to study cooperative drying or processing ventures could emerge from this conference.

5. Because of the swelling world need for protein, we recommend that DOE participate in studies of the use of inexpensive energy sources in processes like those described here for the production of leaf protein for human and animal consumption. Obviously, this has foreign-policy implications: the coincidence in certain foreign countries of the need for food, alfalfa production, and the presence of low-grade geothermal resources should be ascertained.

CHAPTER 3: THE DEHYDRATED ALFALFA INDUSTRY

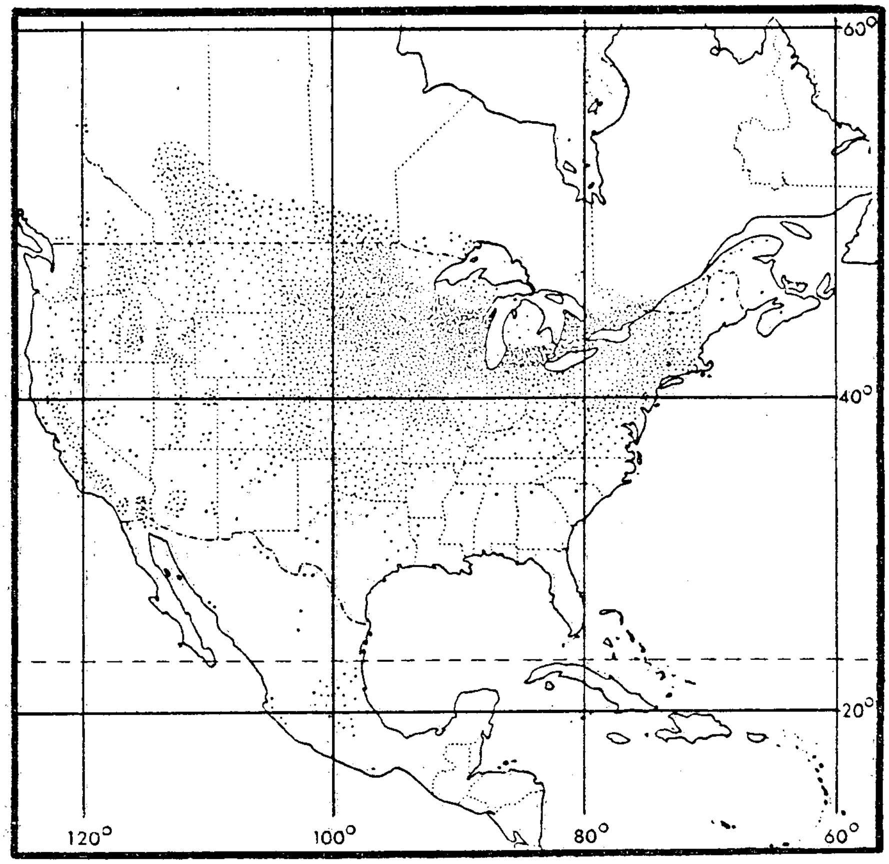
Introduction and Historical Development

Alfalfa as a mainstay of today's agriculture accounts for approximately one third of the hay crop in the United States. As may be seen from Figure 3.1, the crop is grown throughout the country with the heaviest concentration in the Midwest and the Far West. The crop is not native to the Americas, but was introduced here by the colonizing Portuguese and Spaniards of the 16th century. Its probable homeland is Iran, and it was brought to Europe by Greek invaders. Introduction to the United States was made by early missionaries coming from Mexico into Texas and Arizona and California during the mid-19th century. Known as "Chilean clover," alfalfa proved to be of major importance in California during the days of the gold rush.[1]

By 1900 there were two million acres of alfalfa under cultivation, the crop having spread from the western and southwestern states into Kansas and the Midwest. Acreage under cultivation continued to grow rapidly. By 1924 there were 10 million acres devoted to alfalfa; this acreage doubled by 1950, and a peak of 30 million was reached in 1958. Since then the acreage under production has remained somewhat under 30 million acres. Table 3.1 shows the distribution of production of alfalfa hay in the United States by region.

The alfalfa milling industry may be dated from the early experiments of Otto Weiss of Wichita, Kansas, who at the turn of the century started putting ground alfalfa into commercially mixed feeds.[2] He was followed by M. E. Peters of Omaha, Nebraska, whose experiments in mixing ground alfalfa and molasses in the feed served to increase the use of alfalfa in mixed feed preparations. In these early experiments the alfalfa meal was ground from naturally dried or "sun-cured" aerial portions of the alfalfa plant. Demands for a uniform dark green product were sufficient to encourage artificial drying which could assure a high-quality meal. The first commercial dehydrators began operation in the early 1930s. Dehydration proved not only to enhance the appearance of the meal, but to decrease the nutrient losses which result from field drying. Furthermore, the bulk of crop deterioration during the drying period when the naturally dried cut alfalfa lies exposed to threat of rain could be eliminated by processing the alfalfa almost directly following its cutting.

Dehydration thus seemed to provide a better product for feed formulations and to offer the grower better possibilities for crop management. While the principal harvesting of alfalfa is in the form of sun-dried hay (approximately 70 million tons per year), approximately 1-1/3 million tons of a dehydrated alfalfa (generally known as "dehy") are currently produced each year in the United States. The modern dehydrating process removes the moisture rapidly from fresh alfalfa and makes for a portable and storageable forage.



SOURCE: Alfalfa Science and Technology, C. H. Hanson, ed., American Society of Agronomy, Madison, Wisconsin, 1972.

Figure 3.1. Area and Distribution of Alfalfa in North America. Each dot represents 4,000 ha (9,884 acres).

Table 3.1

AREA, PRODUCTION, AND YIELD OF ALFALFA HAY IN USA BY REGIONS, 1969

Region	Area		Production		Yield	
	Hectares	Acres	MT	Tons	MT/ha	Tons/A
North Atlantic States	858,000	2,119,000	4,973,000	5,482,000	5.80	2.59
North Central States	6,764,000	16,715,000	39,748,000	43,814,000	5.88	2.62
South Atlantic States	102,000	253,000	595,000	656,000	5.83	2.59
South Central States	449,000	1,109,000	2,881,000	3,176,000	6.42	2.86
Western States	2,620,000	6,475,000	19,735,000	21,754,000	7.53	3.36
Total	10,793,000	26,671,000	67,932,000	74,882,000	6.29	2.81

There has been a general recognition that crop dehydration offers the possibility of producing a greater yield in dairy, poultry and meat per acre than most conventional feeding systems. Even at present levels of efficiency, the nutrient concentration achieved by crop drying can produce twice as much net energy (starch equivalent) and three to four times as much protein as cereals and oil-seed crops from an acre of land.[3] In this regard dehy, like many other feedstuffs, contributes a complexity of nutrients, vitamins, and minerals to a feed formula. Dehy is rich in amino acids, pigmenting xanthophylls, and the proto vitamins. However, in relation to other crops its energy-to-weight ratio is less than is required in most ratios, and this must be offset by the addition of high-energy ingredients. Nonetheless its contribution to animal growth has kept it as a significant constituent in the feeds of poultry and ruminants raised for beef.

Animal feeds are compounded in an attempt to maximize nutrient qualities and minimize costs. Selection is made from a variety of competing ingredients, with the recognition that most feed ingredients are rich in some essentials but deficient in others. The selection process is complicated by the fact that the benefits associated with a given feed ingredient may not be entirely attributable to identified characteristics of that ingredient. In the case of dehy there are unidentified growth and reproductive factors which make valuable contributions but which have not yet been quantified. The competitive position of dehy is therefore due both to its identified contributions through which it competes with other feed ingredients, and to unidentified contributions which are peculiar to dehy and which for certain feeds (poultry in particular) are felt to be of high intrinsic value. Marginal production costs for dehy, particularly in the area of energy and labor, have hurt its competitive position in recent years. Nonetheless there is felt to be a relatively stable market for the product, providing that these marginal costs do not escalate above the general inflation for agriculture products.

The Dehy Industry in the United States

Dehydrating alfalfa requires the removal of moisture from freshly cut and chopped alfalfa. This moisture removal must be accomplished relatively soon after cutting in order to prevent nutrient loss through the build up of enzyme reactions and the deterioration of the alfalfa through the subsequent production of heat. Approximately four tons of freshly cut alfalfa are required to make one ton of dehy. The drying process occurs through the direct exposure of the alfalfa green chop to intense artificial heat. Further processing includes grinding and pelletizing of the meal.

The rapid expansion of the dehy industry during the 1940s and early 1950s was stimulated by the promotional effort 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 by the gas companies 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 matched the seasonal growth period of alfalfa.

Table 3.2 shows the number of dehy plants in the United States at different periods of time. Since the industry began in the 1930s, 900 to 1000 plants are estimated to have been established.[4] Prior to 1950 additional new plants accounted for increases in annual production. After 1950, however, plant size tended to grow larger. As economies of scale were achieved these plants, operating at high capacity, supplied the increased demand.

Table 3.2

NUMBER OF DEHY PLANTS IN THE UNITED STATES

1941	100
1944	185
1950	500
1954	348
1970	300
1976	250*

*ADA member plants plus estimated nonmember plants.

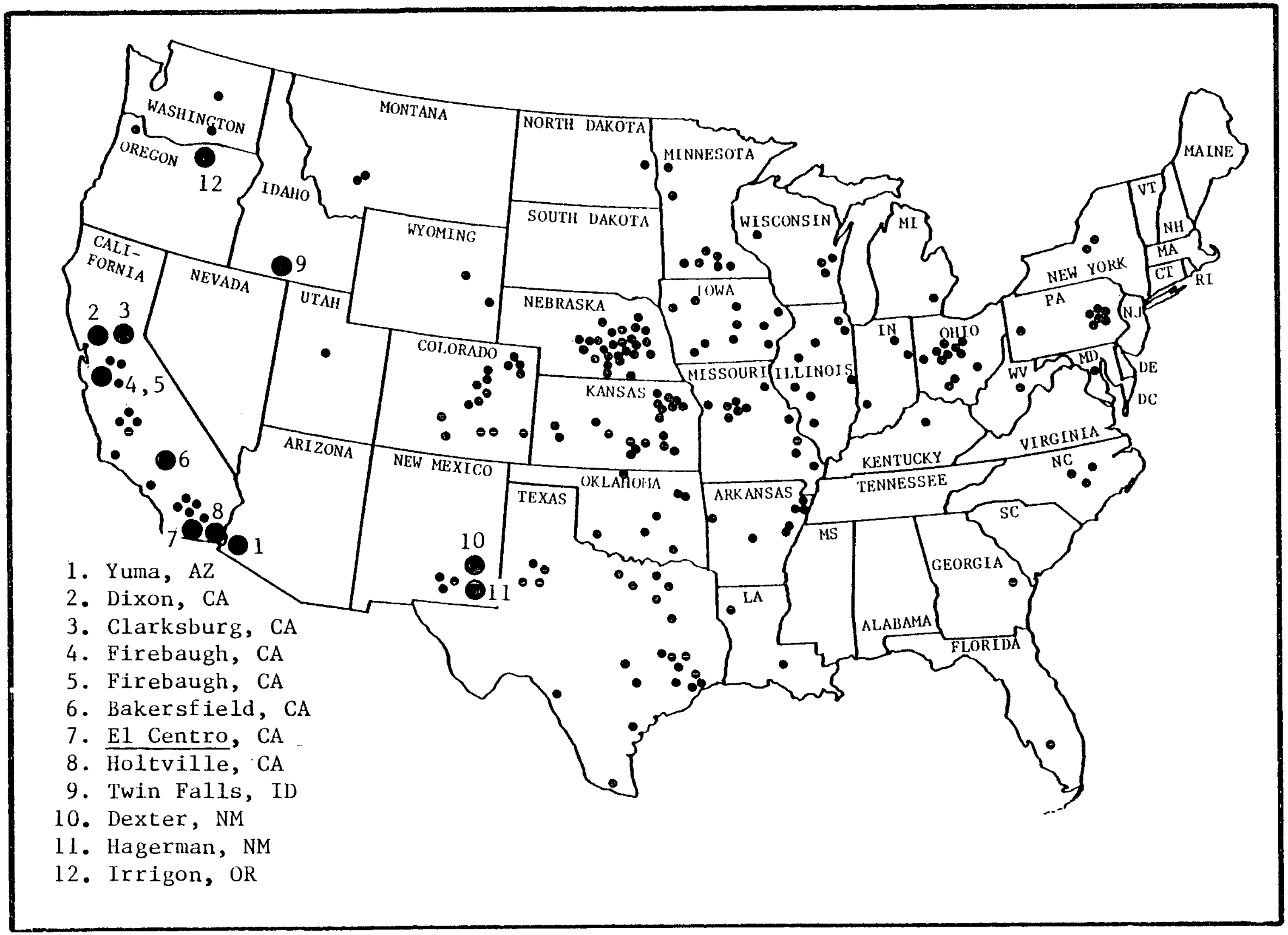
SOURCE: Guidelines for Cooperative Alfalfa Dehydrating Plants.

There are about 250 dehydrating plants in the country at the present time. Reporting of production is not made on the per-plant basis, but rather by individual drum-drying unit; currently there is a total of 426 drums, indicating an average of nearly 2 drums per plant. Most of the dehydrating plants are investor-owned; however, the industry tends to be dominated by relatively few firms in terms of total annual production with about 20 percent producing approximately 70 percent of the annual tonnage.[5]

Figure 3.2 shows the current location of dehydrating plants in the United States. The plants vary in size from less than 1000 dry tons of dehy per year to over 35,000 tons per year, the average being approximately 5000 tons per year.[6]

The American Dehydrators Association in Kansas City, Missouri is the trade association for the industry. (Distribution of member plants by state is shown in Table 3.3.) The organization sponsors programs of research into feeding trials with dehy which have been useful in promoting dehy in a variety of feeds. In addition to providing its membership with current market information, which is a prerequisite for a successful competition in the volatile feed market, the organization also compiles relatively complete statistics on production disappearance including export.

Cooperative dehydrating plants have been attempted by the industry, but by 1970 there were only 10, 20 others having discontinued their operation prior to this date. Since these cooperatives went out of existence at the peak of alfalfa production in the United States, management difficulties appeared to be at least a partial source of trouble. In some instances farmers failed to continue growing alfalfa to provide a steady source of input to the cooperative. Rather, they wish to be free to switch to other crops which may have



SOURCE: The American Dehydrators Association

Figure 3.2. Distribution of Dehy Plants in the United States

Table 3.3

ADA MEMBER PLANTS

Alabama	2	(includes 3 storage plants)
Arkansas	10	
California	2	
Colorado	16	
Indiana	12	
Kansas	40	
Maryland	1	
Michigan	2	
Minnesota	6	
Missouri	7	
Nebraska	77	
New York	2	
Ohio	20	
Oklahoma	5	
Oregon	1	
Pennsylvania	6	
South Dakota	3	
Tennessee	2	
Texas	8	(includes 1 storage plant)
Vermont	1	
Total U.S.	223	
Canada	17	
Other Foreign	18	

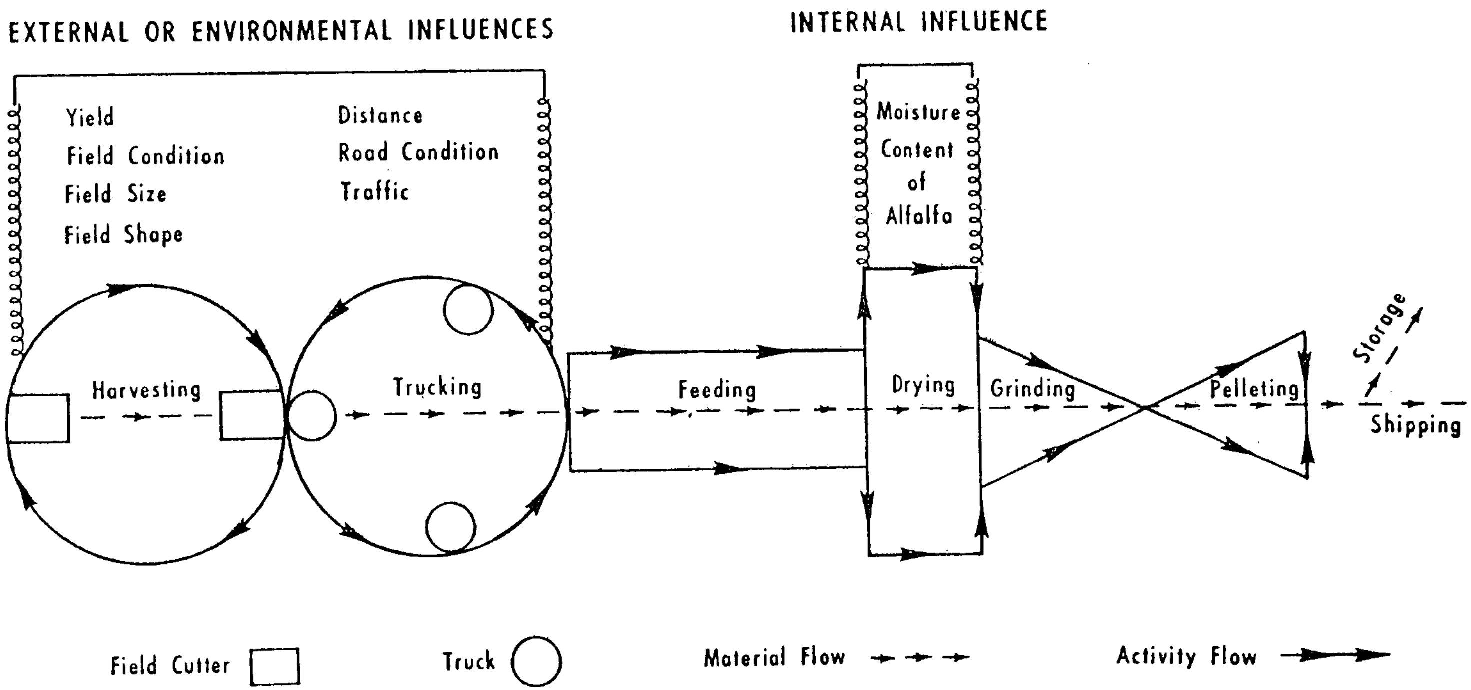
had greater commercial advantage to them, making it difficult for cooperatives to gain long-term commitments from their member farmers in order to stabilize production. However, under good management and with adequate support from its membership, a cooperative can offer a steady market for members' alfalfa, and with good promotional activities can secure a satisfactory price. The Farmer's Cooperative Service of the United States Department of Agriculture has encouraged the formation of such cooperative dehydrating plants.

Figure 3.3 shows the material and activity flows in a typical alfalfa-dehydrating operation. Harvesting is done in fields that are usually dedicated to the dehydrating plant, either through ownership by the dehydrator, or through a leasing arrangement with farmers, whereby the dehydrator controls the harvesting process. In order to maintain adequate throughput in terms of plant production, and at the same time not to harvest the alfalfa prematurely (so that minimum time passes between harvesting and production), control of the harvesting process must be in the hands of the dehydrating plant operator. Generally the distance that the green-chop can be economically trucked to the plant is approximately 10 to 20 miles. At greater distances, not only do trucking costs increase, but the amount of time spent in transportation may have a deleterious effect upon the cut alfalfa through increased enzyme action and heating of the green-chop.

Approximately 2000 acres of alfalfa are required to maintain the production of a typical plant. Harvesting is done in a series of cuttings throughout the growing season, and may vary from less than 5 in the Midwest to 10 or 11 in California in the Imperial Valley, where the crop may be grown all year around. A plant with a one-drum dehydrator may employ up to 15 people during the peak of the season. A typical investment in a 5000 ton-per-year plant was estimated at $182,000 in 1970; economies of scale are revealed by comparison with a plant producing 15,000 tons of dehy per year at approximately $273,000.[7]

The energy requirements for producing a ton of dehy vary between 9000 and 15,000 cubic feet of gas to dry green-chop with a moisture content of between 65 and 85 percent, the average being approximately 12,000 cubic feet per ton for green-chop with an initial moisture content of between 70 and 75 percent.[8] Total industry consumption of natural gas in 1975 using the average figure of 12,000 cubic feet per ton and assuming virtually all drying was done by natural gas leads to a consumption estimate of 17 billion cubic feet. Total natural gas consumption in the United States for 1975 was 20,000 billion cubic feet.[9] Thus, the dehydrating industry consumed less than one tenth of 1 percent of the U.S. domestic consumption of natural gas.

Since the early 1950s the use of pelleting machines has become popular to produce a more easily managed product. Compacting the alfalfa meal into pellets more than doubles the density of the product (alfalfa dehy meal has a density of 16 to 22 lbs per cubic foot; alfalfa dehy pellets have a density of 41 to 43 lbs per cubic foot). The alfalfa pellets can be handled with bulk loading equipment. In general, the pelleting operation produces a reduction in labor costs and a significant reduction in dust levels at the plant. For those customers who wish alfalfa meal, the pellets are reground to order at a slight additional cost.



SOURCE: Guidelines for Cooperative Alfalfa Dehydrating Plants, FCS Information 68, U.S. Department of Agriculture, Washington, D.C., Oct. 1970.

Figure 3.3 Material and Activity Flow in Alfalfa Dehydrating Operations and Factors that Influence Rate of Flow with Equipment of Given Capacity

One of the advantages of dehydration is the possibility of storing the product without significant deterioration. Storage of alfalfa pellets is done in an inert-gas environment which virtually eliminates oxidative losses in the product up to the time of removal from storage. Storage also protects against losses from fire, insects and rodents. Effective storage allows more of the product to be marketed during the winter months when prices will be high. A recent survey has estimated that there are 682,000 metric tons of inert-gas storage capacity in the United States.[10]

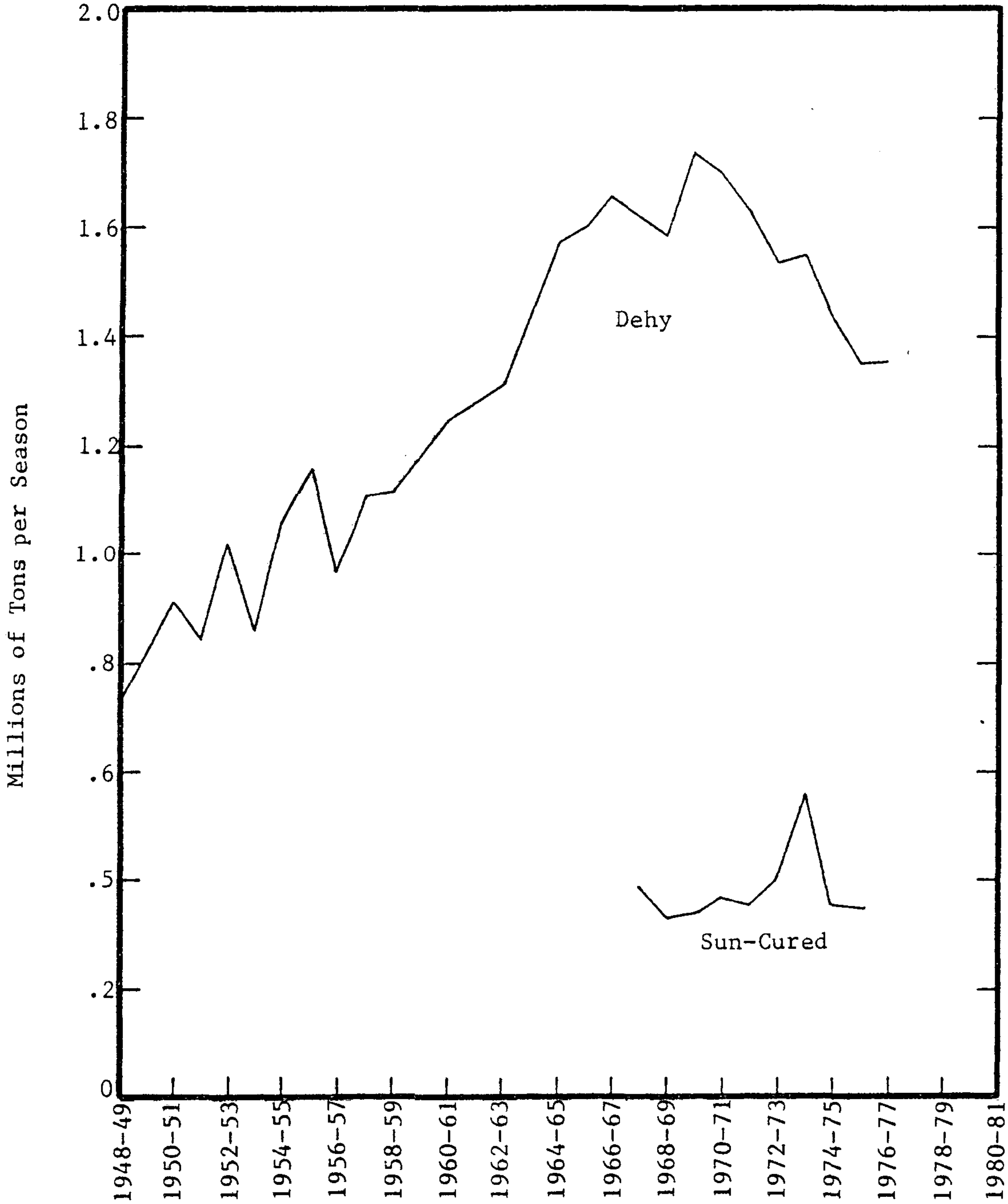
Production and Markets

Dehy production in the United States increased until the 1970s, when a peak production of 1.7 million tons was achieved. As Figure 3.4 and Table 3.4 show, production levels since this time have been falling, dropping to a current value of about 1.3 million tons. Figure 3.4 and Table 3.4 also show the production of sun-cured alfalfa meal for the past 10 years.

Figure 3.5 shows annual exports of alfalfa meal. The principal purchasing country has been Japan, whose imports have accounted for 75 to 85 percent of exported dehy, and upwards of 95 percent of sun-cured alfalfa meal (see Table 3.5).

The quantity of dried alfalfa produced by drying with natural gas exceeded alfalfa sun-cured production in 1946 (see Figure 3.6). Since then, the use of sun-cured alfalfa for domestic purposes has remained well below dehy production. However, as may be seen from Figure 3.5, sun-cured alfalfa has provided a substantial portion of the export market and in recent years had led over dehy exports. The quality of sun-cured alfalfa may vary considerably, but in general, the losses of xanthophyll and carotene are substantial compared to dehy. The market for sun cured in this country has in recent years been for ruminant animals primarily. Sun-cured product exported to Japan, however, is used in poultry feeds. Substantial risks may be involved in loss of the crop due to rain and field spoilage when sun curing is attempted. This, coupled with the need to produce a reliable product, has been a significant factor in accelerating the growth of artificial drying of alfalfa.

The recent decline in the production of dehy can be attributed to several factors. It may be recalled that the industry had been promoted by natural gas companies seeking an outlet for summer sales of natural gas. The tightness of supplies of natural gas in recent years has caused the natural gas companies to cease promotion and, in some instances, to curtail supplies to dehydrators in the Southwest, where the growing season extends into the winter months. Rising energy costs and uncertainties in energy supplies were accompanied by increases in rural labor costs and by problems of availability of rural labor. Along with these uncertainties grain and other cash crops began to compete more strongly with alfalfa. It became difficult in some areas to maintain sufficient alfalfa acreage within an economic radius of the dehydrator.



SOURCE: Dehydrated Alfalfa Production and Disappearance, American Dehydrators Association, 1969.
E. Mengering, American Dehydrators Association, Feedstuffs, Feb. 7, 1977, p. 31.
Grain and Feed Division, Agricultural Marketing Service, U.S. Dept. of Agriculture.

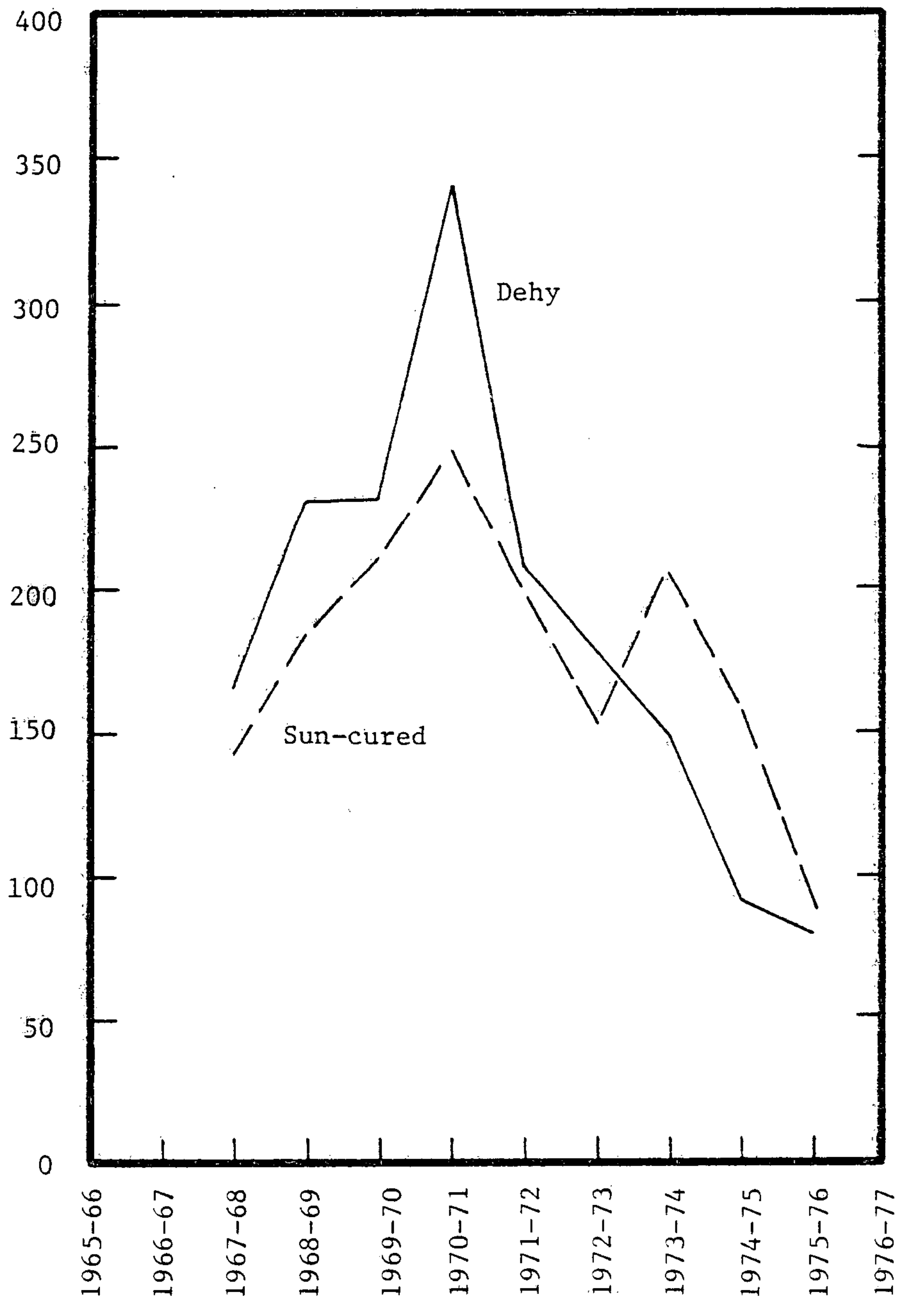
Figure 3.4. Alfalfa Meal Production (May 1-April 30)

Table 3.4

PRODUCTION OF ALFALFA MEAL

Season (May 1-April 30)	Thousands of Tons	
	Dehy	Sun-Cured
1948-49	732.0	
1949-50	800.3	
1950-51	907.5	
1951-52	846.5	
1952-53	1,020.1	
1953-54	855.6	
1954-55	1,063.7	
1955-56	1,163.7	
1956-57	962.3	
1957-58	1,110.7	
1958-59	1,122.9	
1959-60	1,171.6	
1960-61	1,242.0	
1961-62	1,277.9	
1962-63	1,317.8	
1963-64	1,437.5	
1964-65	1,575.0	
1965-66	1,596.7	
1966-67	1,660.2	
1967-69	1,620.9	392
1968-69	1,582.4	323
1969-70	1,737.2	339
1970-71	1,698.1	371
1971-72	1,634.0	359
1972-73	1,538.4	399
1973-74	1,550.5	563
1974-75	1,425.4	358
1975-76	1,353.4	352
1976-77	1,356,500	

SOURCE: Dehydrated Alfalfa Production and Disappearance, American Dehydration Association, 1969.
E. Mengering, American Dehydration Association, Feedstuffs, Feb. 7, 1977, p. 31.
Grain and Feed Division, Agricultural Marketing Service, U. S. Dept. of Agriculture.



SOURCE: Grain Division, Agriculture Marketing Service, USDA.

Figure 3.5. Exports of Alfalfa Meal (May 1-April 30)

Table 3.5

EXPORTS OF ALFALFA MEAL

Annual exports of dehydrated alfalfa and sun-cured alfalfa from May 1 to April 30 are shown for selected countries. (Totals are for all countries.)

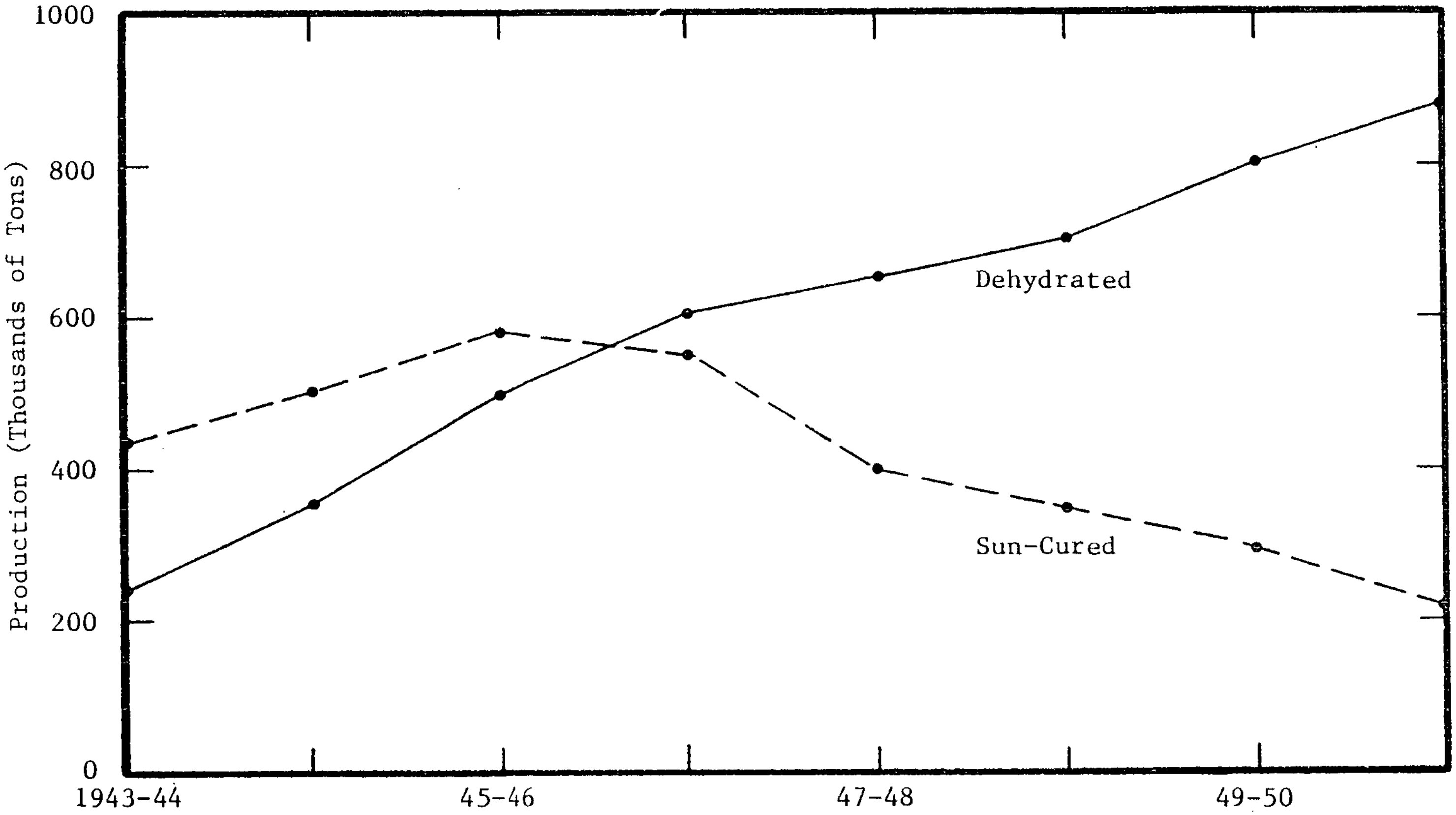
Thousands of Tons

	Dehy		Sun-Cured	
1967-8	Venezuela	12.5		
	United Kingdom	8.3	Netherlands	6.6
	Japan	134.8	Japan	130.3
	Total	164.4	Total	141.3
1968-9	Venezuela	8.9		
	United Kingdom	12.0		
	Netherlands	18.2		
	Japan	177.8	Japan	180.4
	Total	231.7	Total	183.9
1969-70	Venezuela	7.0		
	Singapore	8.8		
	Japan	199.5	Japan	209.3
	Total	232.4	Total	211.5
1970-71	Venezuela	7.6		
	Netherlands	8.8		
	W. Germany	24.5	Netherlands	7.1
	Japan	254.9	Japan	236.4
	Total	341.6	Total	248.4

Table 3.5 (Cont.)

	Dehy		Sun-Cured	
1971-72				
Venezuela	7.4			
S. Vietnam	7.9			
Singapore	7.3			
W. Germany	12.3			
Japan	162.9		Japan	194.5
Total	207.4		Total	196.7
1972-73				
Japan	141.4		Japan	148.0
Total	162.3		Total	152.8
1973-4				
Japan	142.3		Japan	204.1
Total	150.3		Total	206.0
1974-5				
Japan	84.8		Japan	156.0
Total	91.6		Total	159.9
1975-6				
Netherlands	17.6			
Japan	51.4		Japan	81.9
Total	77.8		Total	90.9

SOURCE: Grain and Feed Division, Agricultural Marketing Service, U.S. Dept. of Agriculture.



SOURCE: Dehydrated Alfalfa, Bulletin 356, Agricultural Experiment Station, Kansas State College, Manhattan, Kansas (Feb. 1953).

Figure 3.6. Cross-over in Production of Artificially Dried and Naturally Dried Alfalfa Meal

Improved information on dehy nutrient quality and stability has made it possible to include dehy in feed preparation with reduced margins for safety. This has resulted in a general change in feed-preparation mixing practices. Prior to 1964 the amount of dehy going into feeds was about 3 percent; since then the amount has been reduced to 2 percent.[11]

The role of alfalfa in feedstuffs also has changed with increasing knowledge of poultry genetics. By breeding poultry which could reach maturity in a shorter period, nutritionists were faced with formulating high-energy low-fiber feed. This drastically limited the amount of alfalfa for a feed ration, and for some companies (particularly in California where dehy is used primarily for poultry) this meant a reduction of 40 to 50 percent of their domestic market.[12] (In the Midwest, some of the loss to poultry was made up by increases in the use of dehy in cattle feeds.)

A significant factor in the reduction of dehy production has been a diminution of exports, particularly to Japan. The drop of production for export affected California primarily, which has supplied most of the shipments to Japan. Competition from Canada has been a strong factor in the attenuation of U.S. foreign exports. As a result of the depression of Canadian wheat prices in 1971, the Canadian government promoted and subsidized investments in new alfalfa-dehydrating plants in order to stimulate growth in alfalfa. The Canadian government subsidized these plants with conditional grants of up to one third of their total cost. Canada now produces approximately 300,000 tons of dehy per year; 165,000 tons are exported, nearly all of it to Japan. Paralleling Canadian dehy industry growth, U.S. exports to Japan dropped from over 140,000 tons in the early 1970s (peak of 255,000 tons in 1970) to 51,000 tons in 1975 (see Table 3.5).

In 1976 Europe provided an unexpected market for U.S. dehy. Europe normally produces 1.1 million tons of dehydrated alfalfa per year. France is the dominant producer, with an annual production of nearly 900,000 tons.[13] However, as a result of extreme drought conditions, alfalfa growth fell off for 1976, making it necessary to import large quantitites of dehy.

The price of dehy can vary considerably from one part of the country to the other. Prices will also vary substantially with the season, winter prices being the highest. For the first week in February 1977, 17 percent protein dehy pellets were priced at $111, $127, $139, and $161 per ton at Kansas City, San Francisco, Atlanta, and Boston, respectively.[14]

Historically, dehydrated alfalfa prices have shown somewhat greater fluctuations with time than have the prices of other grains. As may be seen from Figure 3.6, the general movement of alfalfa prices is consistent with the feedstuffs index. The sharp escalation in prices of dehydrated alfalfa along with other feedstuffs beginning in 1973 is largely due to increases in grain exports, particularly to the Soviet Union. While dehy exports did not grow during this period, the general increase in the price of alfalfa, which competed for acreage with cash crops that were being exported, had a primary impact on price of dehy.

Table 3.6 shows the monthly variation in the price of dehydrated alfalfa. As may be seen in this table, there may be considerable variation in price throughout the year, winter prices averaging over 10 percent higher than the average price for the year. The increased prices in the winter, of course, represent costs of storage, which supplies most of the demand for dehy during the winter months. While inert-gas storage allows for the possibility of selling the dehy through the year, it also allows for the possibility of large carryovers into a new growing season. Such carryovers can seriously affect the price of the product. This happened recently, at the beginning of the 1968 season, with a carryover of almost 215,000 tons, nearly twice above normal carryovers. The impact on prices may be seen from Table 3.6 for this period. It is felt that when agricultural products are overproduced even by as little as 5 percent, the value of the entire crop will be set by necessary price reductions needed to sell the last 5 percent.[16] Thus, in the case of selling dehydrated alfalfa, it is necessary to coordinate carefully production and storage so that total product disappearance rates will be at profitable market prices.

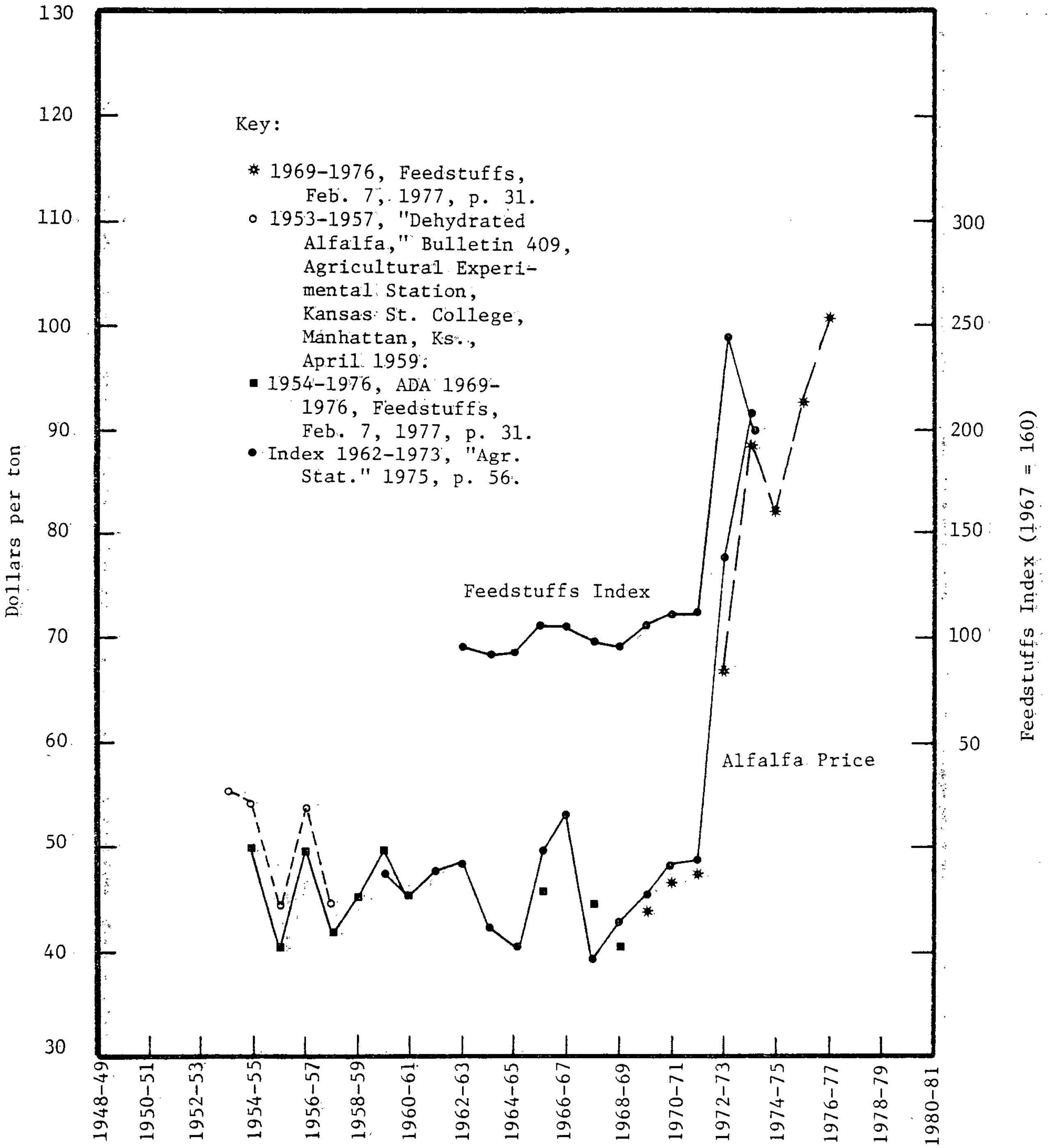
Markets for midwest dehydrated alfalfa are local feed formula manufacturers, livestock feeders, and the large feed manufacturers in the East. Shipments to local markets generally are economical within a radius of 100-200 miles. Shipments are often F.O.B. via truck, though some dehydrators may sell delivery in their own or hired trucks. Transportation to the large central markets (the major domestic feed manufacturers) is usually by rail.

A significant portion of midwest dehy is used in cattle feedlot preparations. While exact figures for the ultimate disposition of dehydrated alfalfa are not available, reasonable estimates indicate that for midwestern dehy approximately 50 percent goes to beef feedlots, between 15 and 20 percent for poultry feed formulations, approximately 15 to 20 percent for swine feed formulations, and a small amount for rabbit feeds.[17] Further west, dehydrators in Colorado sell most of their dehy to Texas feedlots, though a small percentage may end up in east Texas poultry feeds. Dehydrators in the Northwest look to poultry feeders in Portland and Spokane for their markets.

As would be expected in one of the country's leading poultry states, the California dehy market is almost exclusively for poultry feed, though a small amount is sold for rabbit feed. For California, a greater market had been export, particularly to Japan. The fraction of dehy which was exported in California reached almost to 80 percent in the early 1970s.[18] Decline in the export market, however, has made the domestic market of about equal importance at present.

Outlook

The high production reached in 1970 probably will not be equalled in the near future. The loss to Canada (where dehy production continues to be promoted and partially subsidized by the government) of much of the U.S. export market is probably permanent. In the domestic market, dehydrated alfalfa competes with other feed formula ingredients in terms of their respective



SOURCE: 1959-1975, "Agr. Statistics" 1970, p. 58; 1975, p. 56

Figure 3.6. Average Dehy Alfalfa Prices (17% protein dehy, Kansas City)

Table 3.6

Alfalfa Meal: Average Wholesale Price for Dehydrated, 17% Protein, in Dollars per ton, bulk at Kansas City

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	Average
1954-55	40.75	36.00	47.40	44.10	43.35	50.75	53.30	55.60	60.25	62.25	57.40	50.75	50.15
1955-56	35.10	32.10	31.25	32.20	38.40	45.25	42.30	46.50	46.60	44.00	42.10	41.50	39.85
1956-57	37.20	31.50	31.00	36.25	45.75	53.70	57.55	59.10	61.00	63.00	62.00	61.00	49.90
1957-58	39.00	33.75	36.90	43.75	45.50	45.70	46.00	44.20	41.10	42.10	40.60	38.60	41.45
1958-59	32.00	30.75	32.00	31.60	34.70	43.00	46.00	49.00	57.00	61.00	61.00	61.00	44.90
1959-60	54.25	41.60	41.50	43.00	43.40	49.50	53.50	55.00	55.00	55.00	53.40	52.75	49.85
1960-61	43.80	39.00	39.00	41.00	43.00	45.40	47.90	47.10	46.50	46.50	48.10	47.50	44.55
1961-62	46.25	40.75	40.25	43.00	43.00	46.20	49.00	48.00	49.70	52.50	54.00	55.00	47.30
1962-63	44.80	40.00	39.60	43.35	48.00	52.20	54.00	52.25	53.00	54.75	52.25	46.60	48.40
1963-64	41.50	41.25	42.40	45.10	46.25	47.70	49.90	48.80	47.60	45.40	41.20	38.40	44.60
1964-65	37.20	35.20	36.00	38.30	41.00	42.60	43.50	43.50	43.50	41.60	38.80	37.20	39.90
1965-66	36.00	35.60	38.50	41.00	42.20	46.60	49.50	49.50	49.80	52.60	55.20	53.20	45.80
1966-67	43.00	41.50	47.00	50.00	53.00	53.70	56.30	59.60	61.30	61.90	59.50	53.30	53.80
1967-68	46.40	45.90	48.00	47.80	47.00	47.00	47.00	45.70	43.00	39.20	37.20	36.80	44.30
1968-69	36.20	35.50	35.00	33.50	33.50	37.30	41.20	44.40	46.50	47.00	46.50	45.60	40.20
1969-70	41.50	38.80	38.20	40.00	42.10	44.00	45.60	47.20	49.10	48.80	46.40	45.40	43.90
1970-71	43.70	41.90	42.50	43.00	46.00	46.20	48.40	48.90	48.90	49.90	50.70	52.50	46.90
1971-72	49.25	44.60	45.75	46.00	46.00	46.00	46.80	48.75	49.75	49.70	49.70	49.40	47.60
1972-73	49.70	45.80	47.10	48.20	50.00	53.30	62.60	75.70	92.80	106.70	94.80	70.80	66.40
1973-74	71.40	72.70	72.20	74.50	83.20	101.50	103.60	104.70	104.80	102.60	94.20	82.00	88.90
1974-75	75.40	68.20	76.70	93.75	89.75	92.00	89.25	87.00	84.25	77.10	74.40	75.90	82.00
1975-76	77.00	74.70	76.60	81.50	82.60	87.80	92.30	98.70	110.15	110.65	111.40	108.40	92.65
1976-77	91.40	94.20	99.90	101.15	114.20	115.50	111.10	112.15	112.73	111.30			

SOURCE: American Dehydrators Association values for protein, fiber, energy, and vitamins, and how much alfalfa will be used in any formulation is a matter of price and quality relationships with competing ingredients, depending on the nutritional requirements of each specific feed. At the same time, however, dehy is felt to be irreplaceable in many feed formulas because of its unique nutritional characteristics. There appears to be a core market of about 700-800 thousand tons per year which will remain stable. Production has remained nearly constant the last two years (see Table 3.6) and this may represent a relatively stable market provided that production costs (energy, labor, the price of green-chop) do not escalate faster than the prices for other feed stuffs.

Energy cost for drying is an important component of dehy price, representing at least 10 percent of the present price of the product. The possibility of sharp future rises in the price of natural gas and the prospect of gas curtailments (which have already occurred for periods of several days to weeks for some dehydrators, particularly in the Southwest during the winter) have given dehydrators concern about being able to maintain adequate profit margins. Diesel oil is often used as a backup to natural gas, but at current prices of twice that of gas (per Btu) it is problematic whether oil can be an economical alternative.

One technique to save energy costs which may come into widespread use is the wilting of the alfalfa before dehydrating. Letting the cut green alfalfa dry for a period before picking it up for dehydrating can reduce significantly the initial moisture content. (In Kansas, for example, tests of field wilting of four hours reduced the moisture content from about 77.3 percent to 64.2 percent. This results in a nearly 60 percent saving in the energy required for moisture evaporation.)[17] Field wilting, however, does involve the additional expense of a return trip to pick up the cut alfalfa as well as additional capital invested in field equipment, and these expenses have to be balanced off against savings in fuel which will be incurred because of the lower moisture content of the sun-cured hay. Furthermore, wilted alfalfa can be expected to have a lower quality of carotene and xanthophyll due to enzymatic and oxidative losses during wilting. Longer periods of wilting may also involve vitamin and dry-matter losses. The strategy of wilting in order to save fuel costs, therefore, will be dependent upon producing a product whose marketability at a given cost is still consistent with the profit expectations of the dehydrator.

Several recent tests have indicated that field-wilted alfalfa, carefully controlled to allow production of a quality product, showed essentially no differences between the wilted alfalfa and direct-cut alfalfa when fed to ruminants.[18] A similar set of tests shows "the overall quality of carefully field-wilted and dehydrated alfalfa based on nutritional determinants is essentially equivalent to conventional dehydrated alfalfa for ruminant animals, swine, and turkeys."[19] This set of tests did show significant losses in xanthophyll and pointed out that where pigment is desired (that is in broiler and laying hen rations) alfalfa should be purchased on a xanthophyll-guaranteed basis.[20] Western Alfalfa Corporation reports that on the strength of the results of these tests field-wilting drying operations were initiated at its Granada, Colorado plant, where some 31,000 tons of dehydrated alfalfa were produced at an average protein value of 19.8 percent, a vitamin A content of 150,000 I.U. per pound, and a reduction in natural gas usage of nearly 34 percent per ton of product.[21] Currently, field wilting is the most widely used technique for saving energy; it can be expected to grow in importance in the future.

The possibility of dewatering the green-chop through mechanical pressing may come into wider use as an energy-saving process. At present no mechanical dehydrating is done in this country on any large scale, but Europeans have been experimenting seriously with this technique. The dewatering technique produces a nutrient-rich juice from which protein and xanthophyll are extracted by steam coagulation, while the dewatered press cake is dehydrated in a conventional way with a substantially lower energy requirement. The French have been studying this method and have constructed a pilot plant capable of producing two tons of green protein concentrate a day. The technique leads to a considerable saving in drying energy (from fresh alfalfa with 20 percent dry matter 3.5 kilograms of water must be evaporated to produce 1 kilogram of dehydrated alfalfa pellets, while from press cake with 30 percent dry matter only 2 kilograms of water need be evaporated for 1 kilogram of pellets).

The dewatering process and protein extraction technique can also result in the production of white protein, which may be considered for use as an edible for human consumption. Limited feeding trials using similarly produced leaf-protein concentrate have been successful in alleviating kwashiorkor, a severe disorder resulting from protein calorie malnutrition.[22] The possibility of using alfalfa as a high source of protein for humans would ultimately have a large impact on the growth of the dehydration industry, in which protein concentrates would become accepted dietary supplements. Supplying the world demand for protein will require the increased consumption of plant protein. The French see this development as providing a spur to the alfalfa-dehydrating industry. Alfalfa yields a large quantity of protein per cultivated surface area, and the leaf-protein concentrate process is able to provide products having specific uses either for animal consumption or, in the near future, for human consumption.[23]

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CHAPTER 4: COINCIDENCE OF ALFALFA AND GEOTHERMAL RESOURCES

The study began with a detailed investigation into the coincidence of alfalfa and geothermal resources. We were interested in identifying the distance between alfalfa crop growing areas and the geothermal resources that might be used for drying the harvested hay.

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, formed the primary geothermal resource data base. While emphasis was placed on those systems with estimated temperatures between 90° and 150°C, hotter resources were also included. In addition, to extend the data base down to 65°C, an extensive literature search of U.S.G.S. open-file reports and state geothermal surveys was conducted. These data on lower temperature geothermal resources were not analyzed since the economies of alfalfa drying with resources of 90°C and higher did not appear to be attractive.

We also considered the possibility of including normal gradient resources east of the Rocky Mountains.[1] Of particular interest were the Madison and Arbuckle Formations, which underlie portions of the Northern Plains states. Parts of the aquifer systems in these strata probably contain fluids reaching 65°C at reasonable depths. In North Dakota, Nebraska, and Kansas, large numbers of low-output oil wells may offer an unconventional source of geothermal heat: hot water produced along with the oil. Although temperatures are not likely to be high, the locations were attractive. Nebraska is usually the nation's number one producer of dehydrated alfalfa meal (California is second), Kansas is third, and significant production comes from the Dakotas and eastern Montana and Wyoming.

Locating alfalfa growing areas was straightfoward. 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 50-mile circle was drawn, centered on the geothermal resource. (Fifty miles was chosen arbitrarily as the sum of the distance to which geothermal hot water might be transported and the distance from which alfalfa could be transported to such a plant). The 50-mile circles were used to identify counties lying within a reasonable span of the geothermal resources. In all some 275 counties were identified in 11 western states. The 1969 Census of Agriculture[2] was then used to provide information about crops grown in these counties. 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.

It should be understood that this process produced information about agricultural growing locations which were beyond the 50-mile circle. For example, the 50-mile circle might have included only the tip of a county; nevertheless, because the circle touched the county, it was included in our sample.

A summary of our findings appears in Table 4.1. This table contains the top 25 counties, rank ordered by number of tons of alfalfa produced annually.

The most important county is Imperial County, California. This county produces 785,000 dry tons of alfalfa per year from 129,000 acres. The resources which are close to these fields are the East Mesa, Heber, Brawley and Salton Sea KGRAs. In fact, the five top counties are located in California and account for 43 percent of all alfalfa grown in the top 25 counties. As a point of reference, the alfalfa produced by these top 25 counties represents some 6 percent of total U.S. alfalfa production for the year shown, 1969.

Only three of the counties from the list of the top 25 currently have operating dehydration plants. Imperial County, California has two plants; Madera County, California has two plants and Twin Falls County, Idaho, has a single plant. The plants in Madera County, California, are unlikely candidates for retrofit since the alfalfa fields in this county are about 25 miles from the nearest resource. The resource is of low temperature and the reservoir is unexplored. Using quality of the resource, distance between the crop and the resource, and access to transportation as criteria, the resources which have the most favorable outlook as sites for alfalfa dehydrators, either new or retrofit, are:

- East Mesa KGRA, California (new or retrofit of Holtville plant)
- Heber KGRA, California (new or retrofit of El Centro plant)
- Brawley KGRA, California (new plant)
- Salton Sea KGRA, California (new plant)
- Power Ranch Wells, Arizona (new plant)
- Raft River area, Idaho (new plant)
- Bridger Spring area, Idaho (new plant)
- Oakley Warm Spring, Idaho (new plant)
- Northeast Boise thermal area, Idaho (new plant)
- Klamath Falls area, Oregon (new plant)
- Radium Hot Springs, Oregon (new plant)
- Medical Hot Spring, Oregon (new plant)

Table 4.1

TOP 25 ALFALFA-PRODUCING GEOTHERMAL COUNTIES

	County	State	10^3 Dry Tons (1969)	10^3 Acres (1969)	Nearest Resources and Best Estimate Temperature (°C)
* 1.	Imperial	CA	785	129	East Mesa (180), Heber (190) Brawley (200), Salton Sea (340)
2.	Fresno	CA	400	72	Mercey Hot Springs (125)
3.	Kern	CA	341	51	Sespe Hot Springs (155)
4.	Yolo	CA	329	57	One-Shot Mining Co. (150)
* 5.	Madera	CA	244	38	Mercey Hot Springs (125)
* 6.	Twin Falls	ID	241	54	Banbury area (140) Cedar Hill area (120)
7.	Maricopa	AZ	210	38	Power Ranch Wells (180)
8.	Los Angeles	CA	207	33	Sespe Hot Springs (155)
9.	Jefferson	ID	179	55	Newdale area (125)
10.	Riverside	CA	179	29	Pilger Estates Hot Springs (145)
11.	Cassia	ID	175	47	Raft River (140, Bridger Spring area (115), Oakley Warm Spring (120)
12.	Malheur	OR	163	43	Neal Hot Springs (180), Vale H.S. (160), Little Valley area (150)
13.	Canyon	ID	129	20	Roystone H.S. area (150)
14.	Minidonka	ID	128	31	Bridger Spring area (115)
15.	Ada	ID	118	29	N.E. Boise thermal area (125)
16.	Gallatin	MT	118	42	Norris (Hapgood) H.S. (150)
17.	Churchill	NV	107	25	Stillwater area (160) Dixie H.S. (150), Lee Hot Springs (175)

*Indicates dehydrating plant operating in county, 1977.

Table 4.1 (Cont.)

18.	Bingham	ID	106	31	Newdale area (125)
19.	Lyon	NV	105	23	Wabuska H.S. (155) Nevada (Hinds) Hot Springs (105)
20.	Gooding	ID	104	27	Clover Creek area (120), well near Chalk Mine (140), White Arrow H.S. (140)
21	Bonneville	ID	101	32	Newdale area (125)
22.	Madison	MT	101	42	Norris (Hapgood) H.S. (150) Barkels (Silver Star) H.S. (145)
23.	Klamath	OR	98	27	Klamath Falls (120)
24.	Baker	OR	97	33	Radium H.S. (130) Medical H.S. (130)
25.	Millard	UT	96	29	Meadow H.S. (105), Cove Ft.-Sulfurdale (200)

SOURCES: U.S. Bureau of the Census, Census of Agriculture, 1969: Volume I, Area Reports, 1972; U.S.G.S. GEOTHERM data file, Revision B.

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CHAPTER 5: ECONOMIC ANALYSIS OF HEAT TRANSMISSION FROM LOW-TEMPERATURE GEOTHERMAL RESOURCES

Introduction

Two analyses were undertaken in the early portion of this work to study the design and cost 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.[1] The second utilized the GEOCOST fluid transmission submodel developed at Battelle Pacific Northwest Laboratories.[2]

For the parametric analysis, an alfalfa dehydration plant that requires about 15 million Btu's/hr to produce 3 tons/hr of dried alfalfa was assumed as a base case. Heat demands of 50 and 100 million Btu's/hr were also considered in order to assess the effect of scale on costs. Given a geothermal water-rejection temperature of 120°F, 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" (5.6 feet/sec) through the range of standard schedule-40 steel pipes sizes from 4 to 16 inches in diameter. Knowing pipe diameter, and assuming insulation and a 40°F soil temperature, the required wellhead temperature could be calculated as a function of distance. Well cost was $400,000. Basse's approach was used to estimate capital cost of the production and reinjection well system.[3] 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.

Estimates were also made of 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 nonprofit operation. Finally, the cost of heat in dollars per million Btu's was computed assuming 50 percent duty as a base case (4380 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, 16.5 million Btu's/hr, was used. The wellhead temperature parameter was varied from 150°F to 400°F in a series of five variations from the base case. Transmission lengths of 1, 20, and 50 miles were tested and the options of no reinjection and public financing (thus eliminating most taxes) were tried in other runs.

The energy cost for a 16.5 million Btu's/hr demand as estimated by the GEOCOST base-case run agreed quite well with the 15 million Btu's/hr result of the parametric analysis. GEOCOST predicted an energy cost, less heat exchange, of \$13.54 per 10^6 Btu's for 10-mile pipeline transmission; the parametric study showed a cost of about \$14.23. When pipeline length was 1 mile GEOCOST estimated \$6.64; the parametric analysis, \$6.58.

The central conclusions to be drawn from these analyses are: 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 miles at an energy cost 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 retrofitting.

Design Considerations

The flowsheet for the transmission of the hot water and its heat exchange at the usage site is shown in Figure 5.1. The geothermal water is withdrawn from a source well at 150-300°F and transmitted through a pipeline buried about 6 feet into the ground. Booster pumps are spaced periodically to overcome the frictional loss of energy and to raise the pressure in the pipeline above the vapor pressure of the geothermal fluid. At the energy-usage site, the water is cooled by an isobutane secondary loop and returned to the geothermal field by a reinjection well. The isobutane secondary loop is then used to heat the air in a standard air heat exchanger. The isobutane loop was introduced to keep the fouling surface area to a minimum. Since the heat-transfer coefficients for air are much less than for liquids, the surface area for a liquid-air heat exchanger is much higher than for a liquid-liquid heat exchanger. Hence the geothermal fluid is cooled in a liquid-liquid heat exchanger rather than a liquid-air heat exchanger. In addition, the isobutane loop keeps the geothermal fluid surface area low by extracting energy from the geothermal water at a relatively high constant temperature due to changing its phase from a liquid to a gas. If the equivalent energy were extracted without the change in phase, the surface areas in the heat exchangers would have to be increased to compensate for the low temperature difference of the fluids at each end of the heat exchanger. The primary variables in this study are the well temperature, T_0, the distance between the geothermal field and the energy usage site, L, and the total energy demand of the system, Q, in Btu's per hour.

A. Pressure drop in pipeline. The pipe diameter, d, and the flow rate, M, are related by the "economic pipe diameter," where capital costs are balanced against pumping and operating costs. For water, a curve relating the mass flow rate and pipe diameter can be prepared[4] and is given in Figure 5.2. Since the economic velocity for this curve is 5.6 ft/sec, the pressure drop can be calculated and is also shown on Figure 5.2. If a 30 psi pressure drop is assumed between booster pumps, then the spacing between pumps can be calculated from the pressure drop data of Figure 5.2 and is given in Table 5.1.

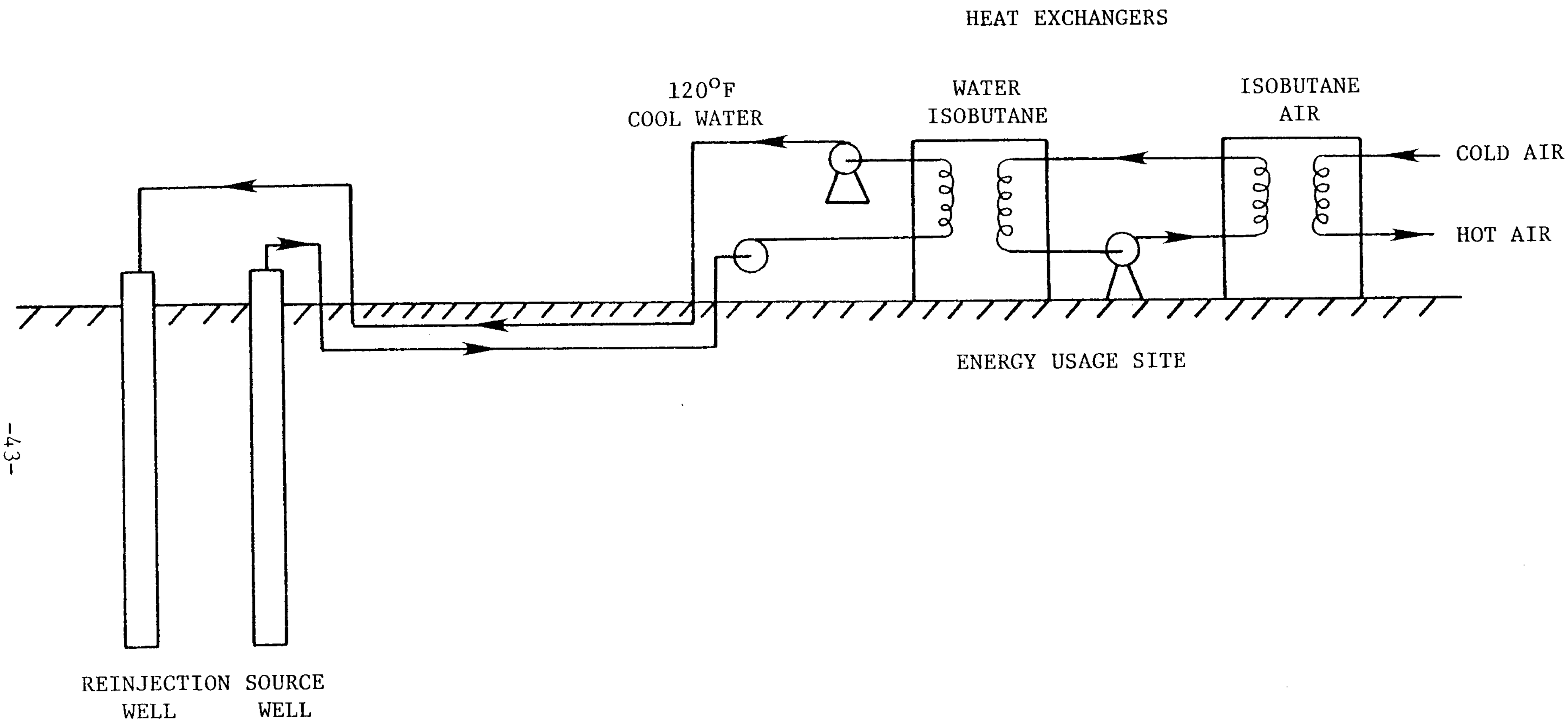


Figure 5.1. Flowsheet for Hot Water Transmission and Heat Exchange

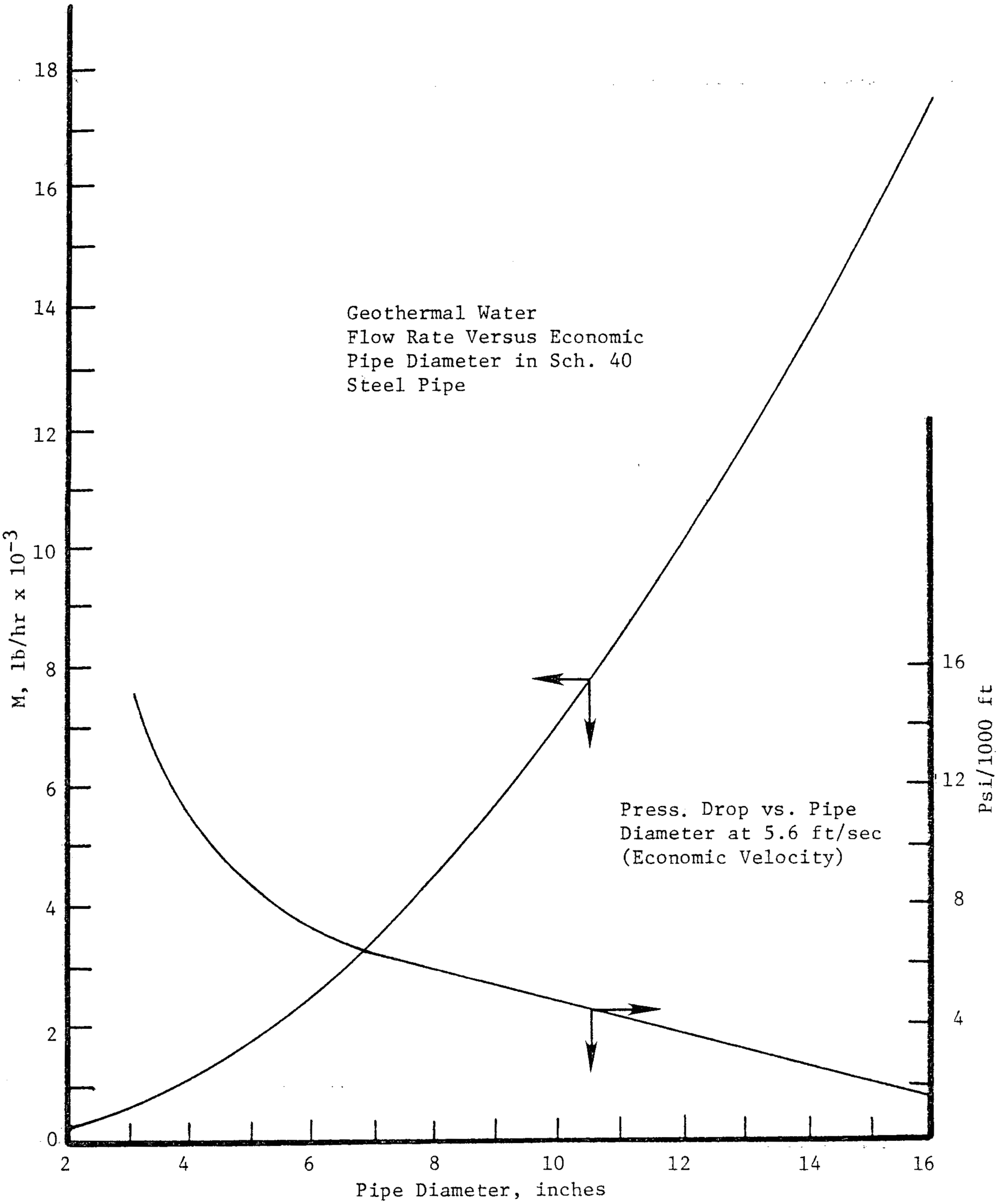


Figure 5.2. Relation of Mass Flow Rate and Pressure Drop to Pipe Diameter

Table 5.1

SPACING BETWEEN BOOSTER PUMPS

Pipe Diameter, inches	Pump Spacing, ft
4	2700
6	4280
8	5172
12	7895
14	11540
16	20000

B. Fluid temperature in pipeline. If an energy balance is written around a differential section of the pipeline, we have

$$\Delta Q = Mc_p \Delta T = - \frac{k\pi da(T - T_s)\Delta L}{x} \tag{1}$$

where
- M = mass flow rate, lb/hr
- c_p = heat capacity, Btu's/hr ft°F
- T = fluid temperature in pipeline, °F
- T_s = temperature of soil, °F
- x = thickness of insulation, ft
- L = length of pipeline, ft
- a = shape factor relating effective heat transfer area to pipe diameter and insulation thickness
- k = thermal conductivity of the insulation, Btu's/hr ft°F.

Integrating Equation (1), we have

$$\ln \frac{T-T_s}{T_o-T_s} = - \left(\frac{ka}{x/d}\right) \left(\frac{\pi}{Mc_p}\right) L \tag{2}$$

where T_o is the wellhead temperature of the fluid.

Assuming that the "true" heat transfer area is a log mean area, the shape factor, a, can be found to be[5]

$$a = \frac{2\ x/d}{\ln(1 + 2\ x/d)} \tag{3}$$

Equation (3) is shown graphically in Figure 5.3. In this study the pipe was assumed to be insulated with polyurethane with $k = 1.9 \times 10^{-2}$ Btu/hr ft°F. For the case of a bare pipe, the effective distance of soil insulation was taken to be 6 feet, and the thermal conductivity of the soil was taken to be 1.3 Btu's/hr ft°F.

For each pipe diameter, Equation (2) will give the fluid temperature as a function of distance from the well source assuming that the mass velocity is that given by Figure 5.2. Since the economic calculations in later sections assumed that the pipe was covered with 2 inches of polyurethane insulation, Figure 5.4 gives the normalized temperature as a function of distance from the well head. To calculate pipeline temperatures, a soil temperature of 40° was assumed.

Capital Cost Estimate

A. Pipeline and well system. One of the important parameters in this study is the demand for thermal energy. Since a medium alfalfa-drying plant requires about 15×10^6 Btu's/hr to produce 3 tons of dry (10 percent moisture) alfalfa, heat duties of 15, 50, and 100 million Btu's/hr were considered. If a geothermal rejection temperature of 120°F is assumed, then the inlet temperature to the water-isobutane heat exchanger can be calculated and is given in Table 5.2.

Table 5.2

HEAT-EXCHANGER INLET WATER TEMPERATURE

Inlet Temperature °F

Heat Duty, Btu's/hr	Pipe Diameter, Inches 4"	6"	8"	10"	12"	14"	16"
15×10^6	270	180	153	141	136	131	129
50×10^6		320	231	191	172	157	148
100×10^6			342	224	195	178	263

The capital cost is influenced greatly by the assumptions about well costs and production rates and any discussion about energy costs should recognize the variability of these items. In this study, the well cost was $400,000 and each well was able to supply 300,000 lb/hr of hot water. The capital cost for the wells, well pumps, gathering lines, reinjection mains and manifolds, operating labor and electrical power for the well pumps and reinjection pipeline, have been correlated with the following equation:[3]

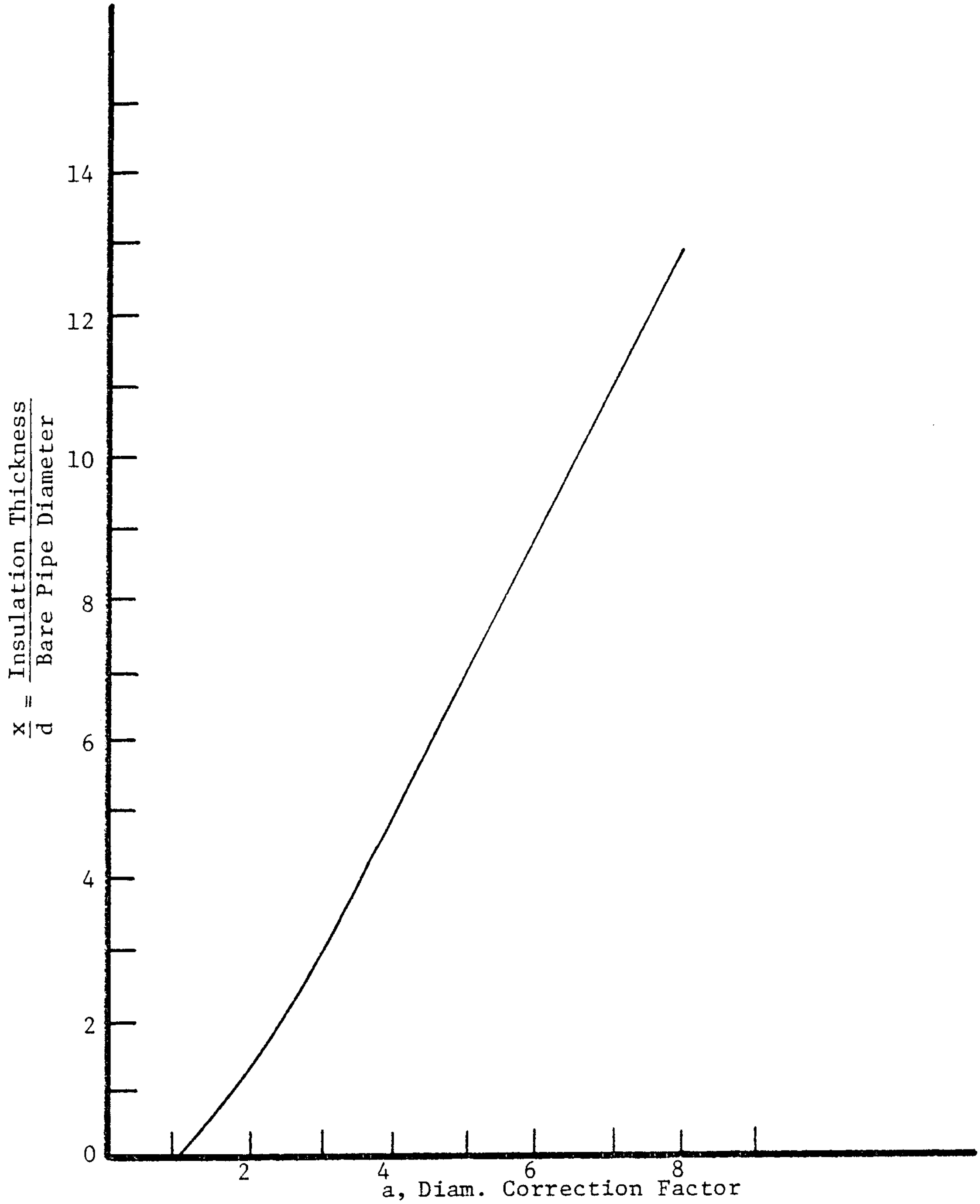


Figure 5.3. Shape Factor, a, Relating Effective Heat-Transfer Area to Pipeline Diameter and Insulation Thickness

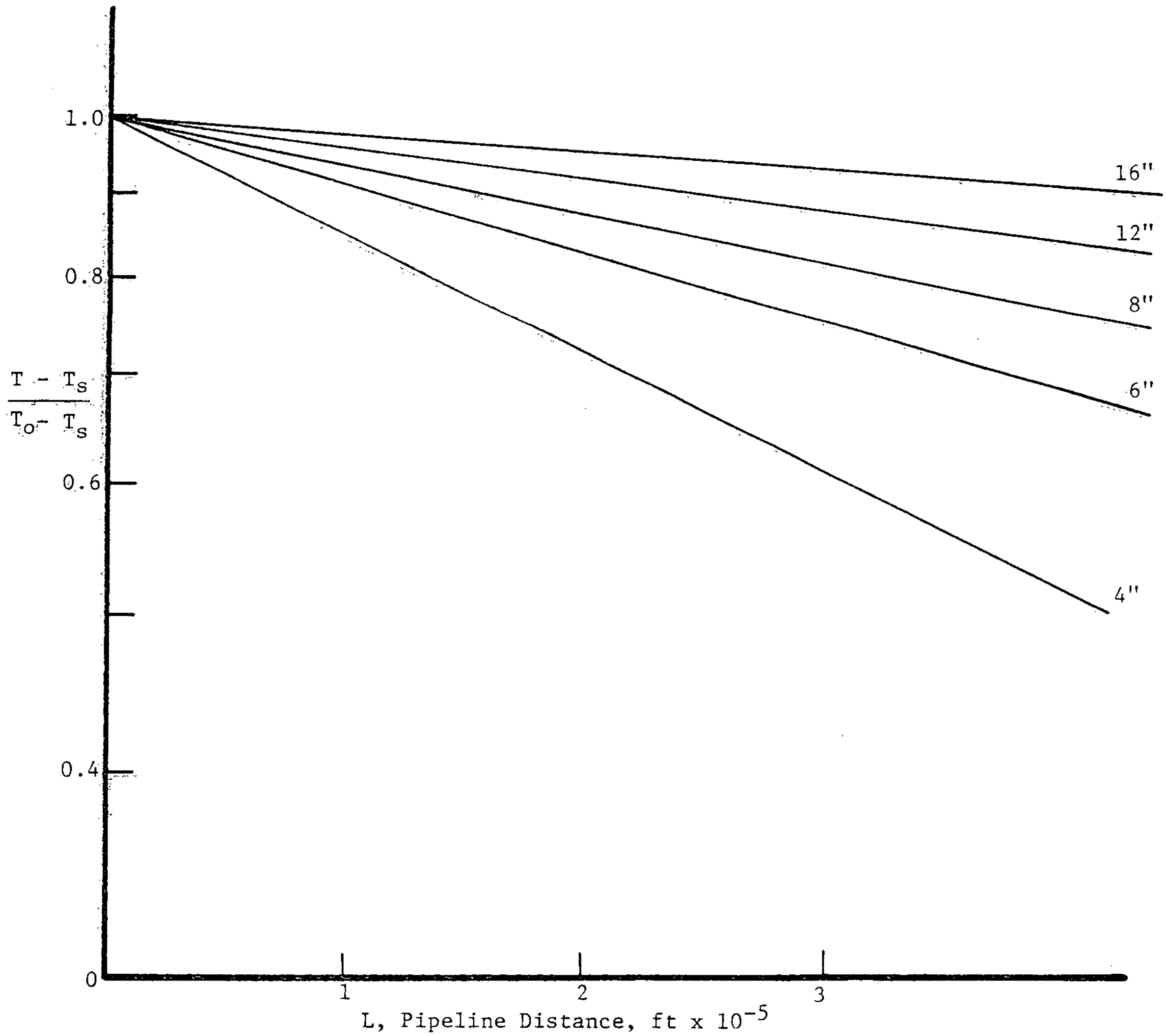


Figure 5.4. Normalized Temperature as a Function of Distance from the Wellhead for Various Pipe Diameters

$$CC_1 = 1.21\ C_w + 1.908n\ C_w + 14960n^{1.217} + 31.65\ n^{1/2}L \qquad (4)$$

where

C_w = the cost/well

n = number of wells

L = length between usage site and well, ft

CC_1 = capital cost of wells and reinjection system, 1975$

Equation (4) assumes: one reinjection well per each two supply wells, 10% well replacement/yr, 10% spare wells, 30 yr straight line depreciation at 8% interest, 20 mills/kw-hr electrical power @ 110 kw/well, 2% taxes, 2% royalty, field development is cost of one well, nonprofit, 10% contingency, and 5.8 people as operating labor with an average rate of $13/hr including overhead.

The capital cost for the pipeline and booster pumps is given by

$$CC_2 = 1.25(\$/\text{ft} \times L + \text{cost/pump} \times \frac{\text{pump}}{\text{ft}} \times L) \qquad (5)$$

where a 25% factor is added to cover controls, valves, engineering and contingency.

The costs in Equation (5) are given in Table 5.3 assuming a base cost of $720/HP for the pumps.

Table 5.3

TRANSMISSION COMPONENT COSTS

Pipe Diameter, in.	Kw	HP	Cost/Pump,$	Pipe Cost, $/ft
4	4.72	6.33	4,558	33
6	11.8	15.82	11,390	39
8	21.24	28.5	20,520	47
12	45.5	61.0	43,920	60
14	63.25	84.8	61,000	62
16	82.13	110.1	79,200	64

The total capital investment required to deliver the hot water is the sum of Equations (4) and (5). Since the capital investment for a given heat duty is only a function of the inlet water temperature and piping distance, the capital investment can be plotted as a parameter when the inlet water temperature and distance are the ordinate and abscissa, respectively. Such curves are given in Figures 5.5, 5.6 and 5.7. The constant cost lines are expressed in millions of 1975 dollars. The dashed lines are the fluid

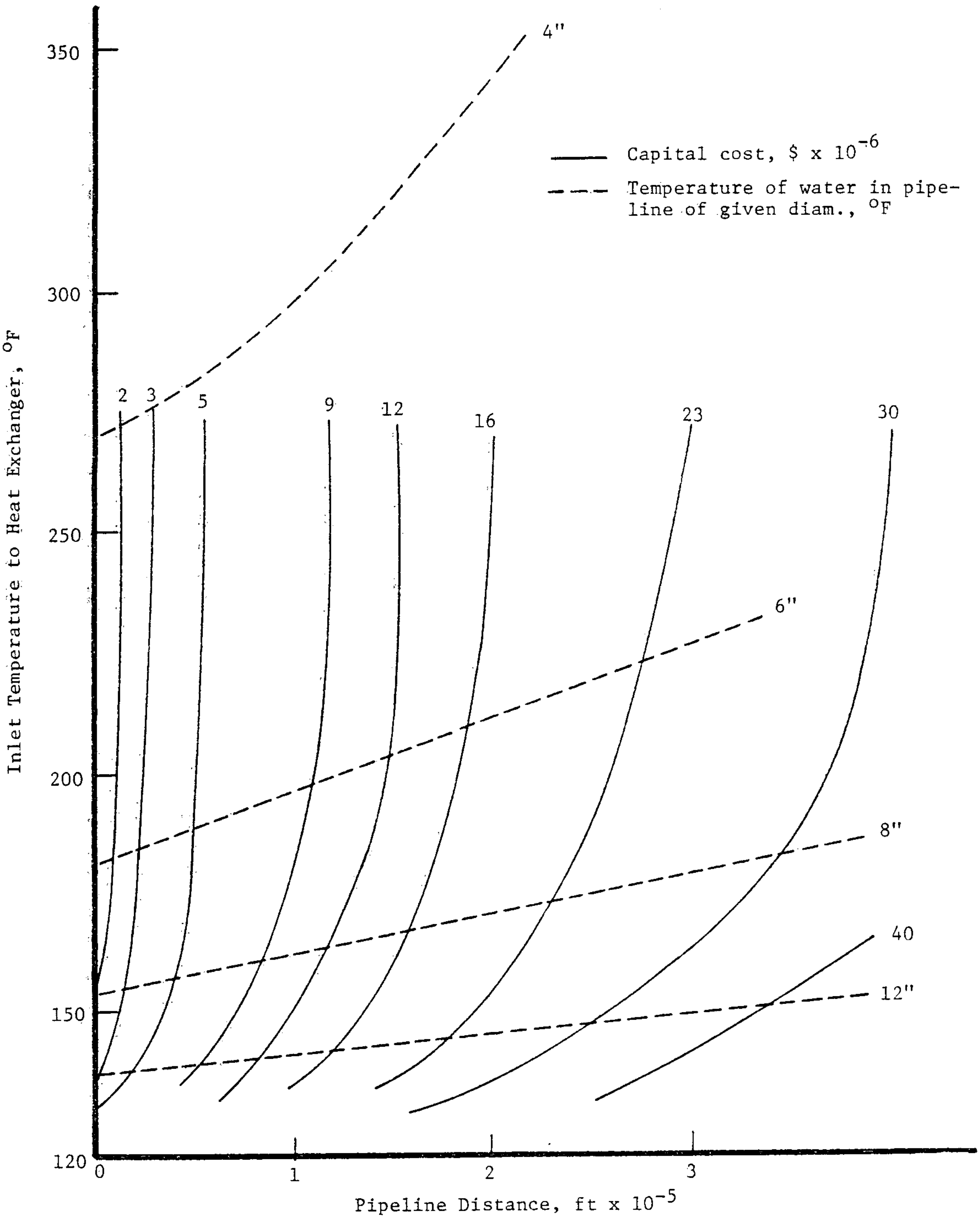


Figure 5.5. Pipeline Capital Cost as a Function of Required Water Temperature at the Plant and Pipeline Distance, 15 million Btu's/hr Plant

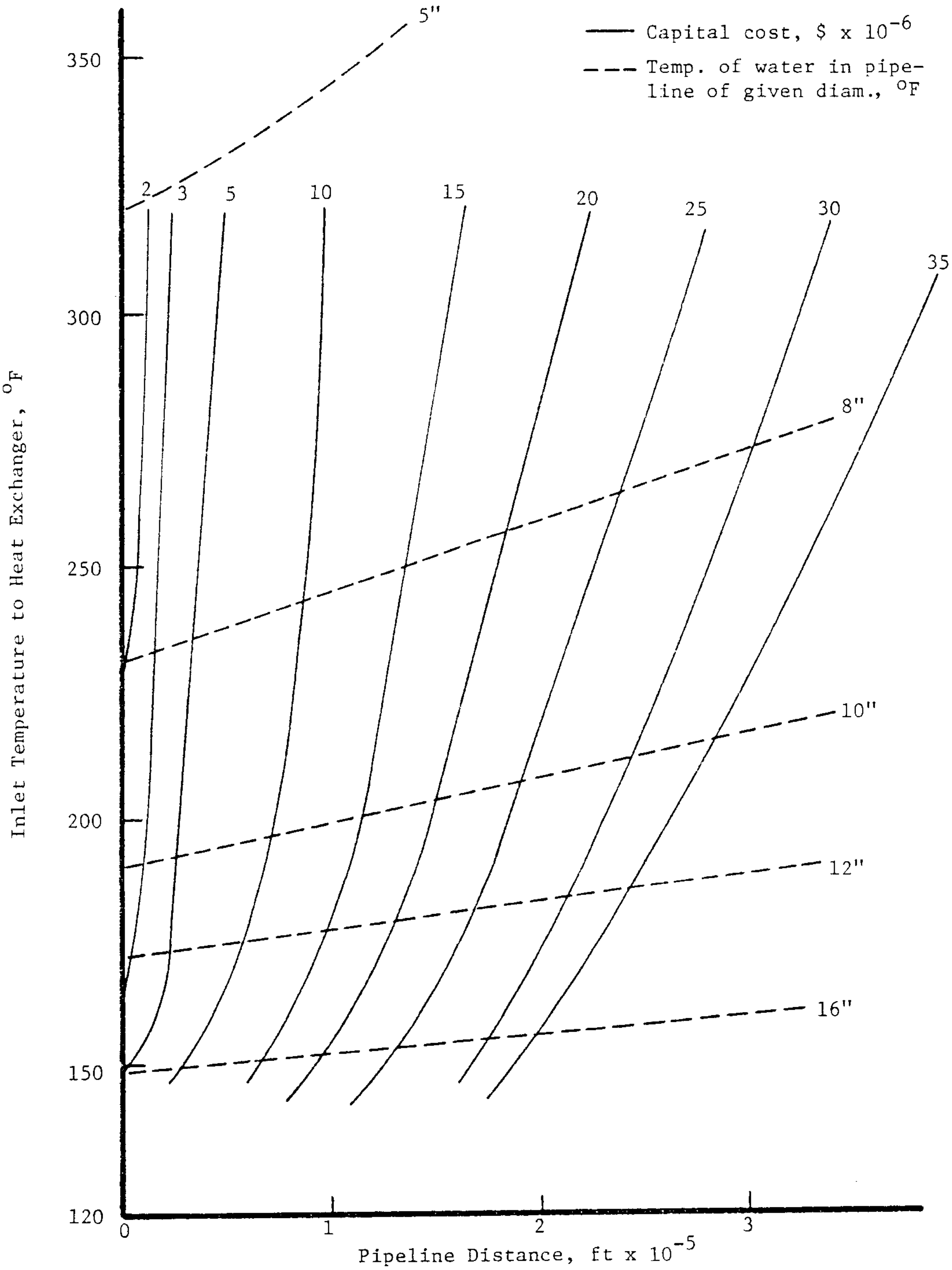


Figure 5.6. Pipeline Capital Cost as a Function of Required Water Temperature at the Plant and Pipeline Distance, 50 million Btu's/hr Plant

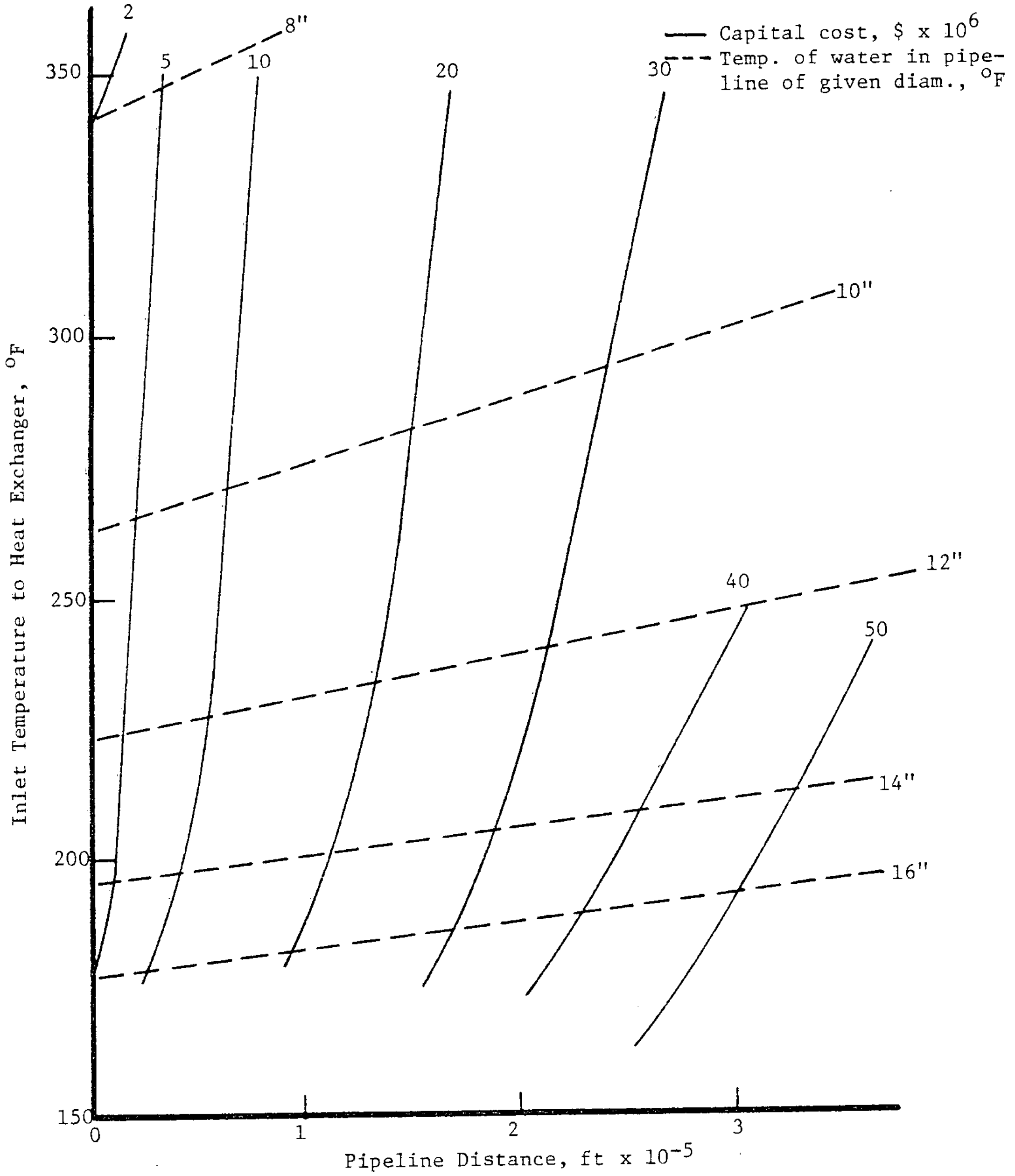


Figure 5.7. Pipeline Capital Cost as a Function of Required Water Temperature at the Plant and Pipeline Distance, 100 Million Btu's/hr Plant

temperature in the pipeline for the given diameters calculated from Figure 5.4. For example, on Figure 5.5, the capital investment required for a 15 x 10^6 Btu's/hr plant using water at 180°F at the plant and coming from a source 100,000 feet away (19 miles) would be $9 million. The geothermal water for the plant would have to come from a well of 194°F.

B. Heat exchanger system. This system is composed of a preheater, a vaporizer with a recycle pump to circulate the isobutane, and an air heat exchanger. The system is showed schematically in Figure 5.8 for the case of inlet water at 270°F. Air is assumed to leave the air heater at 215°F and enter at 100°F.

The overall heat transfer coefficients, U, for the preheater and vaporizer are largely determined by the fouling of the tubes by salt and solid deposition on the outside surfaces. Conventional shell and tube exchangers were assumed for the preheater and vaporizer and an overall heat-transfer coefficient of 110 and 120 Btu's/hr ft^2°F was assumed to hold in each respectively.[9]

The air preheater was designed by the method of Cook[6] using an overall heat-transfer coefficient based upon the non-fin-tube area of 125 Btu's/hr ft^2°F.

Capital cost information was indexed to mid-1976.[7] The installed capital costs for heat duties of 15, 50, 100 million Btu's/hr are given in Table 5.4. The preheater and vaporizer account for about 60-70 percent of the capital cost of the heat recovery systems and unfortunately represent the largest area of uncertainty. New types of heat exchangers using fluidized-bed and direct-contact designs are being investigated at the Idaho National Engineering Laboratory of ERDA and may offer the potential for lower capital investments and less fouling of heat-transfer surfaces.

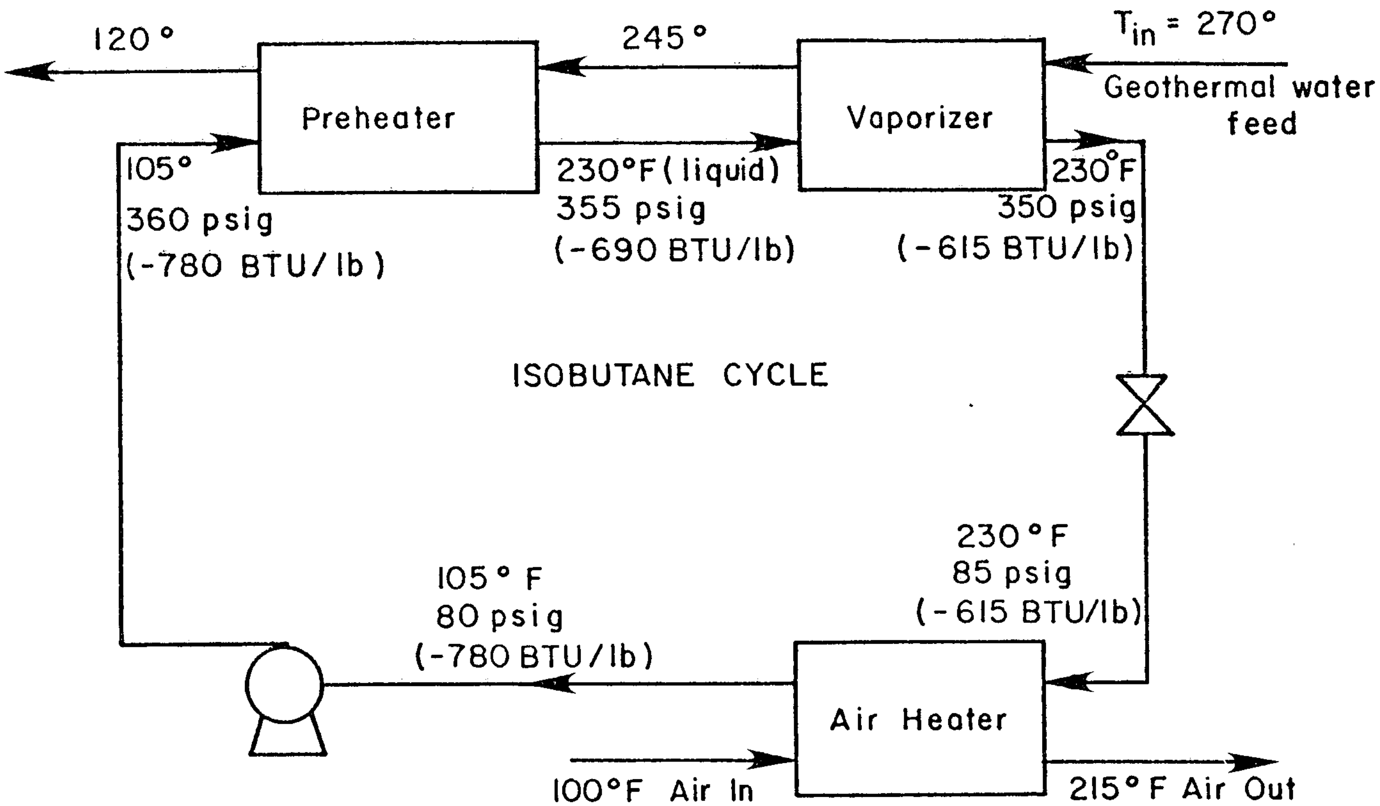
Table 5.4

INSTALLED HEAT-EXCHANGER CAPITAL COST REQUIREMENTS

Heat Duty,	Costs, Thousands of Dollars				
10^6 Btu's/hr	Preheater	Vaporizer	Circulating Pump	Air Heater	Total
15	184	140	41	41	406
50	323	282	99	107	811
100	586	406	180	173	1345

Annual Operating Costs

The annual operating costs (AOC) were determined assuming 30-year straight-line depreciation at 8 percent interest and adding 15 percent of the capital investment to cover materials, replacement, expendable supplies and administrative expenses. The power for the pumps was taken to be $.03/Kw-hr. The system was assumed to operate for 4380 hours/year (50 percent duty). The AOC for the well system has been correlated using the following equation:[3]



(BTU/lb) represent isobutane enthalpy values (7)

Figure 5.8. Schematic of Heat-Exchanger System

$$AOC_1\ (\$/yr) = 0.157\ C_w + 0.398n\ C_w + 1945\ n^{1.217} + 4.109\ n^{1/2}L + 2.226 \times 10^4\ n + 1.302 \times 10^5 \quad (6)$$

The AOC for the pipeline was taken to be

$$AOC_2(\$/yr) = .2388(CC_2) + 131.4\ \text{(total Kw duty of pumps)} \quad (7)$$

The well and pipeline annual cost (AOC) is the sum of the values from Equations (6) and (7). The cost of the energy in $\$/10^6$ Btu's becomes

$$\$/10^6 Btu's = \frac{AOC \times 10^3}{Q \times 4.38} \quad (8)$$

where Q = Heat duty, Btu's/hr.

The cost of the energy from Equation (8) at the use site is shown in Figures 5.9 to 5.11. Generally the cost of the electrical energy to run the booster pumps is negligible in comparison to the depreciation and maintenance factors. It can be seen that the energy costs become very large away from the geothermal source for all heat duties, which would imply that the usage site be located at the geothermal energy source. There is also a large cost benefit in going from 15 to 50 million Btu's/hr demand. When the load factor is less than 50 million Btu's/hr, the thermal output of the one necessary geothermal well is not fully utilized and the depreciation and cost of the capital becomes excessive.

The AOC for the transmission system using 15 million Btu's/hr was also calculated using the GEOCOST transmission model of Battelle Pacific Northwest Laboratories.[10] The GEOCOST results are shown on Figure 5.9 by numbers in parentheses. Their results agree quite well with this study around 10-15 miles but are lower for long distances and higher for distances near the geothermal source. The GEOCOST system used pipe velocities of 10-2 ft/sec instead of 5-6 ft/sec, thus allowing much smaller pipe sizes and hence lower capital investments. Their pipe sizes were 1-4 inches which are at the low end of practicality over long distances. The GEOCOST system also assumed a 10-year well life in place of the 30-year life of this study, which made their power costs higher in the absence of pipeline transmission costs.

The annual operating cost for the heat-exchanger system in a plant using 270° inlet geothermal water is obtained from Equations (6) and (7) and is given in Table 5.5. The cost of power to run the isobutane recirculation pump was found to be negligible.

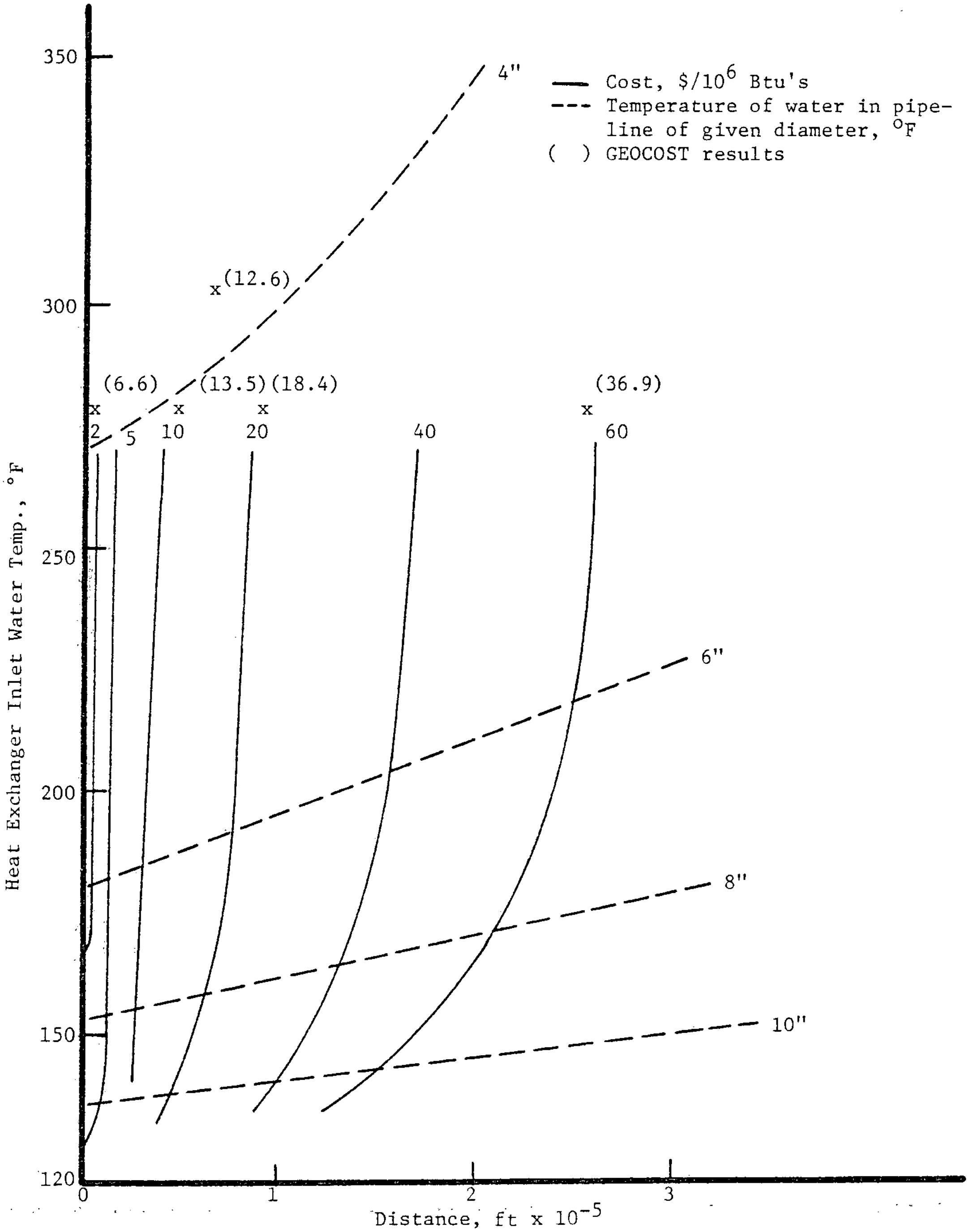


Figure 5.9. Annual Operating Cost Less Heat Exchanger, $Q = 15 \times 10^6$ Btu's/hr

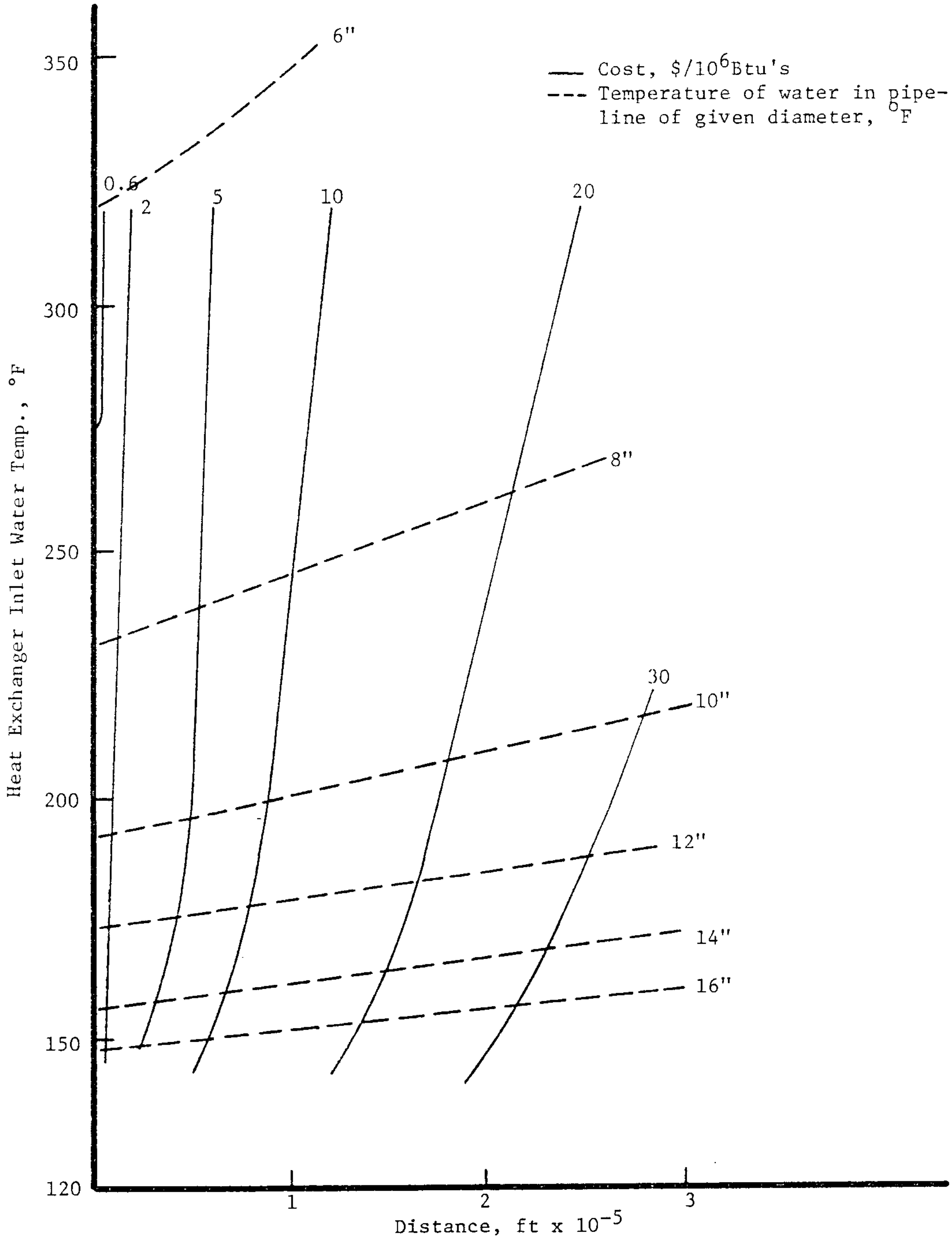


Figure 5.10. Annual Operating Cost Less Heat Exchanger, $Q = 50 \times 10^6$ Btu's/hr

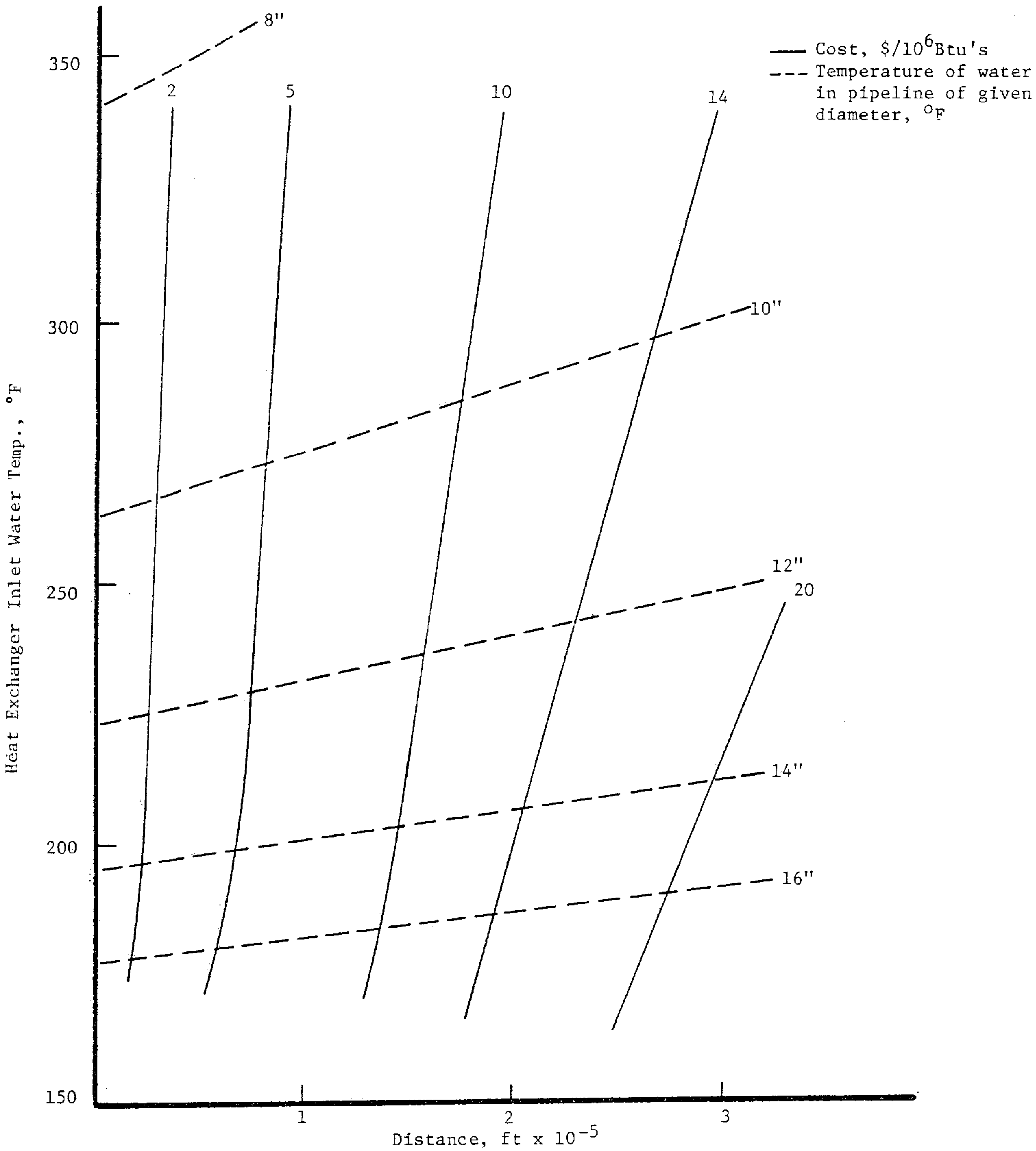


Figure 5.11. Annual Operating Cost Less Heat Exchanger, $Q = 100 \times 10^6$ Btu's/hr

Table 5.5

ANNUAL OPERATING COSTS FOR HEAT-EXCHANGER SYSTEM

	Annual Operating Cost	
Heat Duty, 10^6 Btu's/hr	\$/year	\$/10^6 Btu's
15	97,000	1.48
50	193,500	.89
100	321,000	.73

Since it appears economically infeasible to transport the geothermal water more than a couple of miles, the energy cost for hot air at the well site was calculated assuming 270°F water leaving the well and entering the heat exchanger. For such a system, the costs are given in Table 5.6 where the total annual cost (AOC_T) is the combined annual costs of the well and heat exchanger using Equations (7) and (8). The economies of scale are clearly seen to become important for plants above 50 million Btu's/hr, where the thermal capacity of one well is fully utilized. Since the price of energy is inversely proportional to the percent of utilization, the costs of Table 5.6 could be lowered by having utilization above the 50 percent level assumed in Table 5.6. The projected geothermal energy costs, around \$2/10^6 Btu's, are near the present cost for new and imported natural gas. Therefore, should the natural gas availability decrease, or should the price significantly increase, geothermal systems could become competitive. However, this optimism should be tempered by the need for new heat-exchanger designs to handle the corrosive and scale-forming geothermal fluids.

Table 5.6

ENERGY COSTS AT WELL-SITE FOR HOT AIR FROM A 270°F GEOTHERMAL WELL

Heat Duty, 10^6 Btu's/hr	No. Wells, n	AOC_T, \$/yr	\$/10^6 Btu's
15	1	4.73×10^5	7.20
50	1	5.69×10^5	2.60
100	2	8.81×10^5	2.01

Summary

This analysis established the following results:

1. With the parameters assumed, long-distance transmission of low-temperature geothermal water is not practical beyond 2-3 miles. Beyond 2-3 miles, the cost is almost linear with distance.

2. The economies of scale are very important and energy demand should be greater than 50 million Btu's/hr.

3. Heat exchanger costs are a significant contribution to the energy cost and research to find new designs should be continued.

4. For a 50 million Btu's/hr plant located at a geothermal source of 270°F, the cost of hot air to run a dryer is $\$2.60/10^6$ Btu's.

5. For agricultural drying operations requiring greater than 50×10^6 Btu's/hr and located at a geothermal source, geothermal energy costs are in the range of $1.50 to $3.00 per million Btu's and could become economically competitive.

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CHAPTER 6: GEOTHERMAL ALFALFA DRYER DESIGNS

Introduction

Three means for dehydrating alfalfa using geothermal heat were identified. The first was geothermal "augmentation" in which the drying air is preheated geothermally and then raised to the conventional rotary-drum temperature of 500 to 1000°C (1000 to 1800°F) by natural gas combustion. The second method was to use a different type of dryer with an air temperature of about 150°C (302°F) so that geothermal water could provide all the heat required. Finally, we investigated a large heat pump to raise the temperature from geothermal fluids enough to provide high-temperature inlet air to a conventional drum dryer.

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 Fahrenheit was studied and rejected from serious consideration in this project. Several heat pump manufacturers were contacted, but none knew of an off-the-shelf or prototype unit capable of boosting heat flows on the order of 10^7 to 10^8 Btu's/hour to the required temperature, 1000 to 1800°F. Many expressed the opinion that such a heat pump would be extremely inefficient, and therefore prohibitively expensive, even if geothermal inlet heat were free.

Midwest Research Institute[1] conducted technical feasibility analyses of six specific heat exchanger/dryer combinations. Four of the dryer schemes are of the geothermal augmentation type. A fifth utilizes a geothermal, steam-tube predryer with a drum dryer to complete the dehydration process. The sixth drying system involves a conveyor or belt-type dryer. In addition to MRI's preliminary work on the conveyor dryer, full details of the similar geothermal alfalfa plant at the Broadlands field in New Zealand were obtained from the engineering firm that designed it. This plant is described at the conclusion of this chapter.

The first of the six configurations was a "base case," involving geothermal augmentation. It used a secondary loop coupled to a simple air heat exchanger to provide preheated air to the drum dryer. Both steam and isobutane working fluids were considered. If the drum dryer system consisted of two Heil 105 drums with a combined capacity of 6 tons/hour of dried alfalfa, then about 11.5 percent of the heat required for drying (to the standard dehy moisture content, 10 percent by weight) could be supplied by geothermal heat. By way of comparison, this is somewhat more natural gas saving than provided by exhaust gas heat-recovery systems for these gas drum dryers.

The second system utilized a turbine-driven compressor to drive a heat pump that in turn generates preheated air at a higher temperature than Case 1. The turbine is driven by the expansion of the isobutane secondary fluid;

heat for expansion is geothermal. This unit is commercially available as the "Magma Max." Five heat exchangers are required for the entire system, making it quite expensive.

Case 3 is similar except that steam is used to drive the turbo-compressor. A less-expensive steam flash tank substitutes for one of the heat exchangers. This system was not found to be more promising than Case 2 since brine-flow requirements increased substantially while equipment cost declined little.

In Case 4 two steam flash tanks are used in an integrated system to drive the turbine and to provide steam for the heat pump working fluid. Equipment requirements are considerally simpler than for Case 2.

Case 5 consists of a steam-tube rotary predryer using geothermal steam, coupled to a conventional natural-gas-fired drum dryer. The link between the two might be a fixed mechanical conveyor, or the two could be located some distance apart. If a dehy plant were to be converted to geothermal this could permit the steam-tube dryer to be located at the geothermal source, while the drum dryer, pelleting mill, and rail-loading facilities could remain at the rail siding. Of course, additional transportation between predryer and the main facility would be required.

Case 6 considered a system similar in principle to the conveyor dryer used by the Broadlands Lucerne Company, New Zealand. It substituted drying time for temperature, and while expensive, appears technically feasible.

Alternative Drying Systems

This section presents a description of the three types of dryer systems considered most feasible for direct utilization of geothermal energy--single- or multiple-pass drum-type dryers, conveyor-type dryers, and fluidized-bed dryers. Principles of operation of each system are described as well as advantages as applied to alfalfa dehydration and geothermal heat utilization.

Drum dryers. The conventional alfalfa-dehydration process in this country uses gas-fired drum dryers. This is basically a high-temperature drying process; hot gases pass directly from the combustion chamber through an intake tube into the drying cylinder at temperatures ranging from 1000 to 1800°F, depending on the moisture content of the material to be dehydrated. The majority of the fuel used (93 percent) is consumed directly in dehydrating the alfalfa (see Figure 6.1).

Energy consumed in dehydration in rotary dryers varies considerably depending on dryer design, drying temperature, and feed conditions, primarily total moisture. A reasonable lower limit for drying alfalfa "green-chop" in a direct-fired rotary dryer with natural gas fuel seems to be about 9.5 million Btu's per ton of product meal,[6] although production statistics suggest that actual gas usage is frequently 20 to 25 percent higher than this.[2] Green-chop contains between 70 to 85 percent moisture by weight.[7]

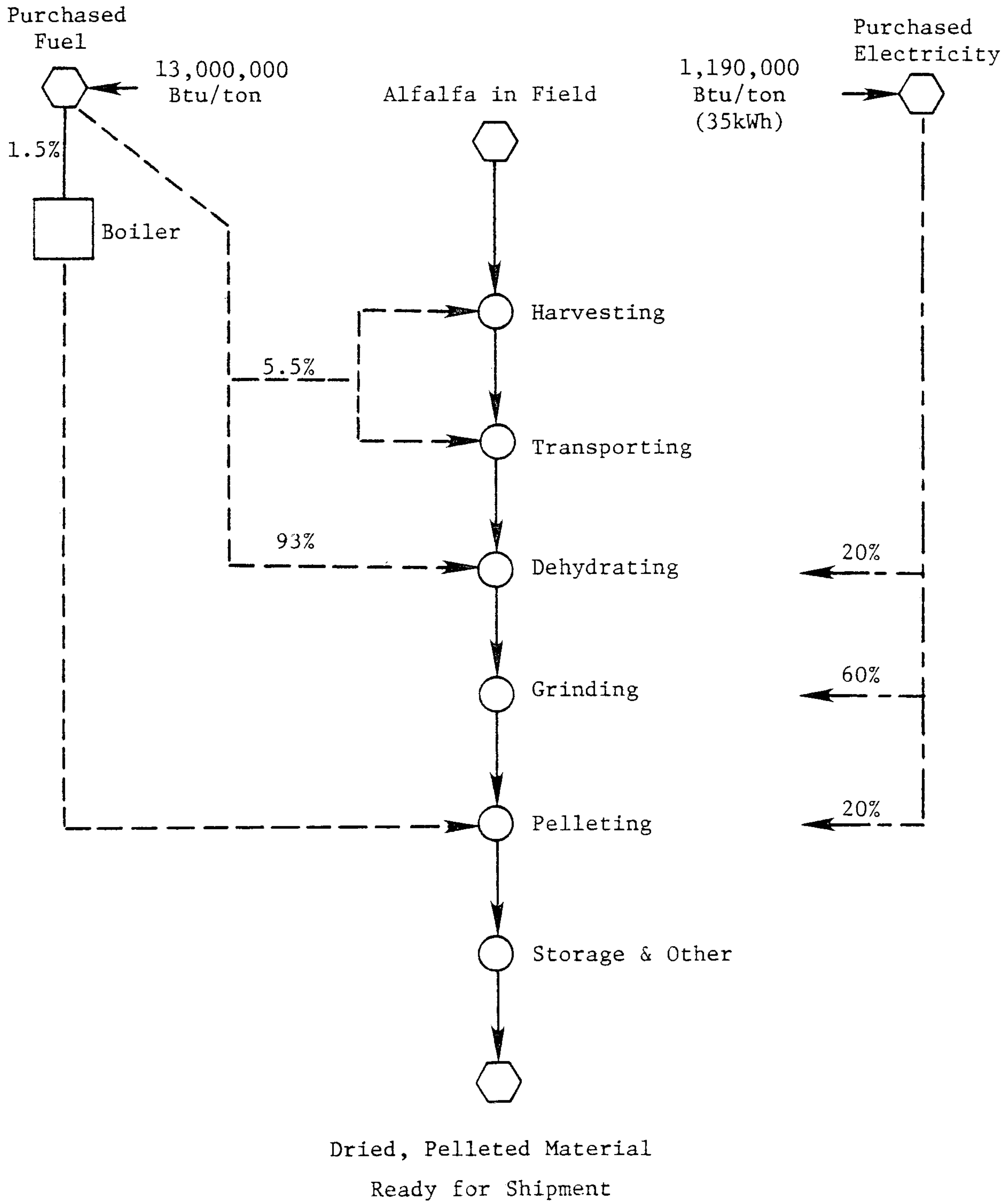

Figure 6.1. Material and Energy Flow for a Typical Dehydrated Alfalfa Plant. (Energy units in Btu's per ton of dehydrated alfalfa.)[5]

The major sources of dryer inefficiency apparently result from discharging the drying gases, alfalfa product, and dehydration moisture at temperatures which are higher than ambient (Table 6.1). For this reason, a significant portion of the dryer fuel can be saved by recirculation of the hot gases and several plants currently use this practice.

In the conventional operation of the direct-fired rotary dryer, the combustion process serves chiefly to heat the dryer air. The volume ratio of combustion air to total combustion gas volume is approximately 27 to 1. This means that nearly all (about 96 percent) of the heat required for drying can be provided by preheating the air prior to combustion. Potential savings in fuel which can be realized by preheating the dryer air using geothermal or other energy sources is shown in Table 6.2.

In conventional practice, rotary dryers are operated with gas inlet temperatures in the range 1500 to 1800°F for feed moisture contents of 70 to 85 percent. Since the dryer operates cocurrently, dryer efficiencies decline markedly at temperatures lower than this. Recently there has been some attempt on the part of the dehydration industry to reduce fuel consumption by partially "wilting" the alfalfa to 60 to 65 percent moisture prior to dehydration. In order to prevent scorching, it is necessary to operate the dryer at lower temperatures in the range 1000 to 1200°F when drying field-wilted material. Under these conditions dryer efficiency drops, on the average, to about 80 to 90 percent of that observed at higher temperatures.[2] Computer simulation of the rotary dryer indicates that operation of the conventional dryer system is not feasible in the range of 120 to 320°F (Chapter 7). In summary, the cocurrent direct-fired rotary dryer, operated at gas (drying) temperatures from 1500 to 1800°F and residence times of 3 to 5 minutes, although still the most widely used, has as its only advantage the minimization of capital investment. This design is economically feasible only at low fuel prices. Two practical methods of using low-level energy sources (50-160°C) to augment the direct-fired dryer are (a) to preheat dryer air; and (b) to recirculate exhaust gases. However, energy savings that can be realized in this manner are, at most, 20 to 30 percent of the total energy requirement.

Conveyor-type dryers. These were formerly used for alfalfa dehydration in this country and for drying of alfalfa as well as other grasses and grains in Western Europe, and in the United Kingdom.[3,8] There are many different types of conveyor dryers (also referred to as "belt" or "band" dryers) which may operate either in single or multiple pass but these are generally low-temperature, countercurrent systems (about 200-300°F).

An example of a conveyor dryer currently manufactured in this country by the Procter & Schwartz Company (Philadelphia, Pennsylvania) is shown in Figure 6.8. The material to be processed is fed onto the feed end of the moving conveyor by means of a variety of preforming and feeding machines. Conveyors are available in a variety of woven-wire and perforated-plate designs. Heated or conditioned air is circulated at a uniform velocity either up or down through the material by means of turbine-type fans. Heated air is typically supplied using steam, gas, oil or waste heat. Food-processing applications for the Procter & Schwartz system include animal feeds, onions, nuts, cereal products, apples, yeast, soya protein, carrots

Table 6.1

SOURCES OF THERMAL INEFFICIENCY
IN ALFALFA DEHYDRATION (ROTARY DRYER)*

	Mechanism	Percent of Gross Heat Input
1.	Heat air and combustion products	11.5%**
2.	Heat alfalfa	1.7%
3.	Vaporize H_2O	59.7%
4.	Heat evolved H_2O	5.2%
5.	Other losses	21.9%

*Basis: Heil SD-105-32 direct-fired, triple-pass rotary drum. Capacity at 75% moisture is 6.0 tons/hr (product basis). Gas consumption is 57.2 million standard cubic feet (scf) per hour natural gas. Discharge temperature is 275°F.

**Natural Gas Composition--90% CH_4, 5% C_2H_6, 5% N_2 (by volume). Theoretical combustion air is 9.41 scf air per scf natural gas.

Table 6.2

POTENTIAL SAVINGS IN DRYER FUEL
BY PREHEATING COMBUSTION AIR (ROTARY DRYER)*

Combustion Air Temperature, °F	Percent of Total Energy**
100	1.6
200	6.8
300	12.1
400	17.3
500	22.6
1500	91.2

*Basis: Heil SD-105-32 rotary dryer, 75% moisture in alfalfa.

**Theoretical values.

and potatoes. Approximately 80 percent of all drying applications involve low-temperature heat sources in the range 250 to 300°F. Variable-speed dryers and air-temperature controls are available for conveyor dryers, making this type of dryer particularly flexible.

Reasons for the demise of the low-temperature dryer in this country for alfalfa dehydration are presently unknown, although capital costs for a conveyor dryer are believed to be somewhat higher than for a direct-fired rotary system of equivalent capacity.[9,10] Operating and maintenance costs may also be a factor. Earlier systems built in the United States and in Europe tended to be of considerably smaller capacity than required by the new plants built in recent years, although the Procter & Schwartz system discussed previously is available in units of comparable capacity. The Procter & Schwartz dryer is a single pass system with the capability for air recirculation. The dryer can be built to operate either cocurrently or countercurrently.

Of particular relevance to the present study is a multipass conveyor dryer currently being operated at the Broadlands field in New Zealand.[11] The Broadlands dryer is designed to operate using 100 percent geothermal steam at 350°F to produce dehydrated alfalfa. Dry air is heated to 200 to 290°F in a heat exchanger. Such a low temperature drying system would be extremely well-suited to the use of low temperature geothermal resources and this system is examined in more detail later in this chapter.

Conveyor dryers offer a number of potential advantages over conventional rotary drying systems. For example, the conveyor dryer permits the variation of feed rates and air flow rates fairly easily, thus facilitating the dehydration of crops having different moisture contents. Some designs (e.g., Procter & Schwartz) include provisions for air recirculation, which allows for greater efficiency. It is sometimes believed that low-temperatures drying systems are inherently less efficient than high-temperature dryers, although studies of actual dryer performance have not confirmed this (see Table 6.3).

In summary, it does not appear that high-temperature dryers have a noticeable difference in thermal efficiency compared with low-temperature conveyor drying equipment employing recirculation. The only advantage of the high-temperature dryer seems to be a slightly lower initial cost when both are fired with the same fuel. The conveyor dryer has a significant advantage in that it is well adapted to the use of low-temperature geothermal and other alternative energy sources.

Other drying technologies. There are numerous other drying technologies which appear to be better suited to crop drying using geothermal energy than rotary dryers. One of these, indirect drying using rotary steam-tube dryers, is commonly used for grain drying for the brewing industry.[10] The steam-tube dryer incorporates a series of steam tubes, fitted along the shell in concentric circles and rotating with the shell. The solids pass along the inclined shell and leave through ports at the other end. A small current of air is passed through the dryer to carry away the moisture, and the air leaves almost saturated. In this arrangement the wet material comes into contact with very humid air, and surface drying is therefore minimized.

Table 6.3

A COMPARISON OF ENERGY CONSUMPTION OF THREE DRYERS OPERATING AT DIFFERENT INLET AIR TEMPERATURES

Make	Type	Inlet Air Tempera-ture, °F	Specific Heat Consumption Btu's/lb H_2O		Heat Losses, percent
			Theo-retical	Manu-facturer's Figure	
A	2-stage conveyor recirculating	320	1330	1640	19
B	Pneumatic	842	1380	1796	23
C	Pneumatic drum	1800	1375	1710	19.5

This type of unit is well suited for use with geothermal energy since it uses the total fluid flow. Steam-tube dryers have a very high thermal efficiency,[12,14] and are readily available in corrosion-resistant materials.[14] The rotary steam-tube dryer concept is examined in more detail in a later section of this chapter.

There are two other concepts which are not studied in detail here. The first involves using the geothermal fluid directly as the drying medium. Paradoxical as it may seem, steam may be used directly to dry many materials, thereby eliminating the costly heat exchanger required by most indirect drying schemes. At comparable temperatures, steam is nearly two times as effective for dehydration as air, on a per-unit-weight basis. This concept can be used effectively only when dealing with a "clean" fluid, and some testing would be required to prevent product contamination. The second concept is fluidized-bed drying which has several potential advantages:[12]

- Close temperature control may be maintained, due to uniformity of bed temperature and the heat-sink effect.

- Retention time may be any reasonable value, depending on requirements for the material. Occluded moisture may thus be effectively removed.

- Simultaneous drying and size-classifying may be done.

- Floor-space requirements are small.

- Several units may be stacked for operations such as combined drying and cooling, or for countercurrent effect to improve heat economy.

- Gas recirculation is possible because the unit is easily sealed. Superheated vapors or inert gas may be used for drying.

- Structural requirements are minimized, as there is no dynamic structural load.

The purpose of the preceding discussion is to point out the numerous drying technologies that are feasible for dehydrating alfalfa and other crops. Some of the methods that are feasible for alfalfa dehydration are not currently being practiced for various reasons including, particularly, the marginal state of the industry.

Dehydration Plant Baseline Design

Our baseline dehydration facility was assumed to include two drying drums each capable of evaporating 18,000 to 20,000 pounds of water per hour and consuming 30 to 35 million Btu's per hour. An installation of this type could produce approximately 16,000 tons of dehydrated alfalfa per season utilizing green-chop or 22,000 tons utilizing field-wilted alfalfa.[13]

A specific drying system was selected for analysis of design options which involve a rotary dryer. The system chosen to meet the above drying requirements was the Heil dryer, Model SD105-32. Two dryers are required to achieve baseline production of about 6.0 tons per hour (dry basis). A description of the "baseline" drying system follows.

The Model SD105-32 agricultural dehydrator has an automatically controlled, rotary-flame furnace, with a combustion chamber fired by oil or natural gas. Hot gases pass directly from the combustion chamber through the intake tube and enter the inner drum cylinder at a temperature ranging from 1000 to 1800°F, depending upon the moisture content of the material to be dehydrated. An automatic cold-air damper is provided to prevent overheating.

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 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 60 feet, insuring complete utilization of heat through radiation from each cylinder.

After the material passes through the drying drum it is blown into the large drying collector, where the vapor-laden air escapes out the top, into the primary cylinder, 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 into the hammermill, as required. Figure 6.2 shows a schematic of a typical dehydrating plant; the product flow differs somewhat from the above description.

Dryer specifications which are required for evaluation of design alternatives are summarized in Table 6.4. From the information presented in this table, baseline efficiency is about 60 percent (percentage of total energy consumed which is theoretically required to evaporate moisture). This efficiency level is probably slightly higher than that currently achieved at most dehydration plants.[2] Efficiency declines when drying field-wilted material which has been prewilted to a moisture content less than about 65 percent. Because direct-fired rotary dryers operate cocurrently with both feed and hot combustion gases entering at the same end of the dryer, it is necessary to reduce drying temperatures to prevent scorching the partially dehydrated feedstock. Energy efficiency may, under these conditions, drop to 50 percent or less.[2]

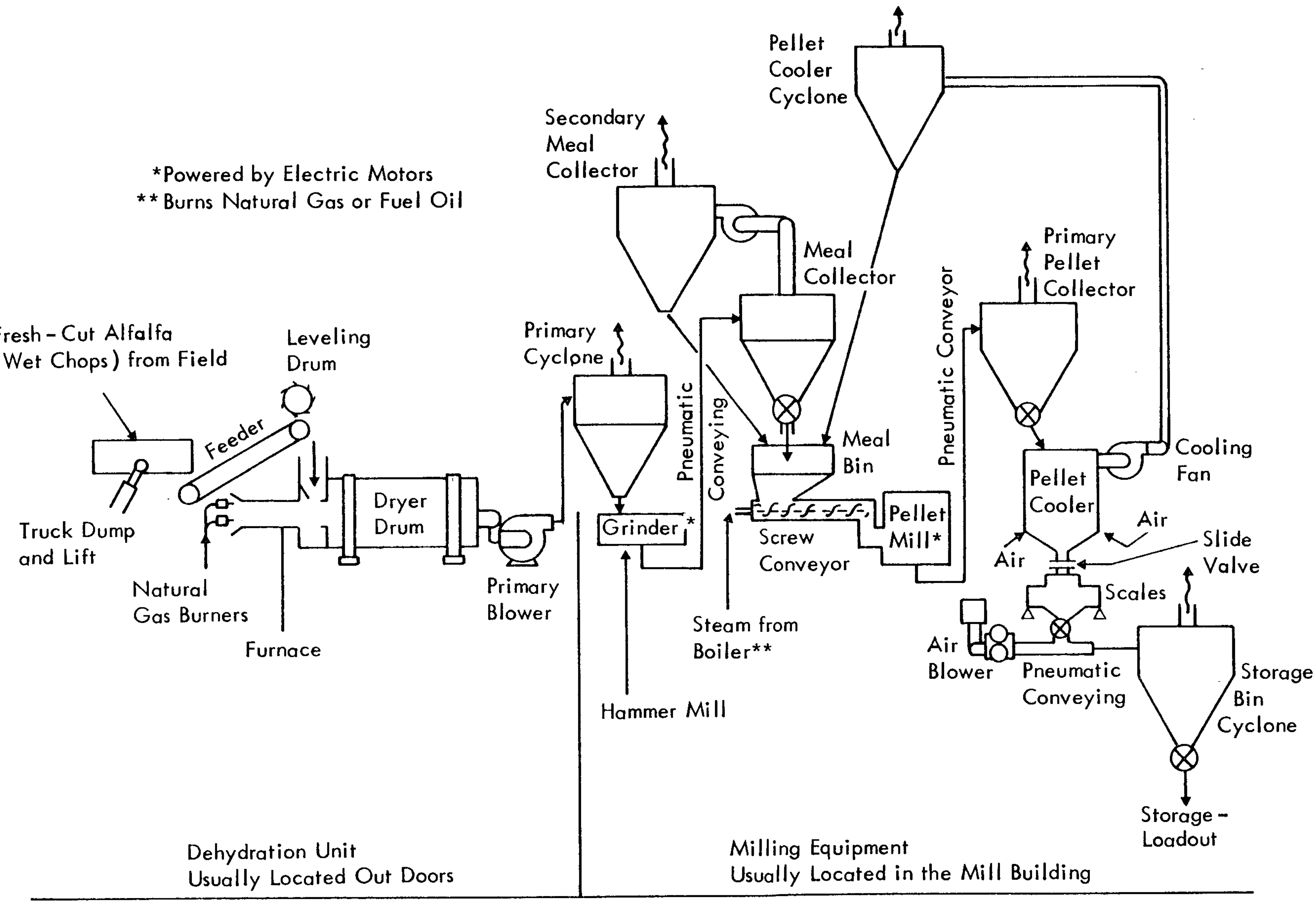

Figure 6.2. Schematic of Alfalfa Dehydrating Plant

Table 6.4

SPECIFICATIONS OF HEIL AGRICULTURAL DRYER
MODEL SD105-32 ("BASELINE" CONDITIONS)[10,15]

Evaporation rate - 18,000 lb/hr of water when initial moisture content is 70% or greater by weight.

Dehydration product - 6,800 dry lb/hr at 10% moisture when operating on fresh chopped alfalfa containing 75% moisture prior to drying.*

Fuel consumption - Maximum natural gas consumption is 28,000 scf/hour.

Fan speed - 1,800 rpm

Fan pressure drop - 7.0 inches H_2O for standard air (70°F).

Back end dryer flow - 28,000 acfm

Discharge temperature - 275°F

Equipment cost (FOB) - $128,289**

*Capacity will vary widely depending on moisture content, type of forage, length of chop, material handling, and size reduction. Capacity reduced approximately 6% for each 1,000 ft increase in altitude above 3,000 ft.

**Cost includes drum, drum base, furnace, in-feed conveyor, feeder, lift apron, main fan, and primary cyclone.

Because various dryer designs were evaluated for use with geothermal energy, and because rotary dryer performance depends on feed conditions and desired product specifications as well as dryer design and operating conditions, it is necessary to specify physical properties of alfalfa green chop and product "dehy" in order to obtain meaningful comparisons among different alternatives. This information is presented in Table 6.5.

Within the range of physical properties shown in Table 6.5, energy requirements for rotary dryers vary with feed moisture content. Production statistics indicate that dehydration of field-wilted alfalfa (60 to 65 percent moisture) consumes on the average 0.54 to 0.60 times the energy required for drying green-chop (70 to 85 percent moisture).[2] At 75 percent moisture and physical properties shown in Table 6.5, two Heil SD105-32 rotary dryers consume approximately 57.2 million Btu's per hour to produce 6.0 tons per hour of dry product. Under these conditions, the dryer efficiency is approximately 60 percent.

It is anticipated that, under the same conditions, the low-temperature conveyor dryer will be slightly less efficient than the rotary dryer by about 10 to 40 percent, depending on inlet air temperature and the extent of recirculation used.[16,17] Other types of dryers have different performance characteristics, and it is necessary to evaluate each system individually to determine energy requirements corresponding to the baseline specifications.

Technical Feasibility Evaluations

Three approaches involving six distinct cases were evaluated for dehydrating alfalfa using geothermal heat. The first approach is geothermal "augmentation" in which the dryer used is of conventional design and the drying air is preheated geothermally and then raised to the conventional rotary-drum temperature of 1000 to 1800°F by natural gas combustion. The second approach involves the use of large-capacity heat pumps to increase temperature input to the dryer above that which is possible without compression. Finally, different types of dryers were evaluated that use only the low-temperature brine as the energy source. Corresponding to the three general approaches outlined, six separate design cases were evaluated as described on the following pages.

- Case 1. Geothermal augmentation using a brine-to-air heat-transfer system: This concept could involve either a single heat exchanger or an intermediate working fluid, as shown in Figure 6.3. Preliminary design calculations indicated that a 300°F geothermal brine could be used to furnish 11.5 percent of the total energy requirement of a Heil SD105-32 rotary dryer, when drying alfalfa with 75 percent moisture.

- Case 2. Geothermal augmentation using a heat pump driven with a Magmamax isobutane turbine: Preliminary design investigations disclosed that the use of a large-scale power conversion system could

Table 6.5

ALFALFA DEHYDRATION FACILITY DESIGN SPECIFICATIONS

Dehydration capacity

- Alfalfa - 6.0 dry tons/hr*
- Moisture - 36,000 lb/hr
- Energy - Variable**

Feed specifications (green chop)

- Moisture - 70-85% (75% av.)***
- Bulk density - 42 lb/ft^3
- Particle density - 53.0-59.3 lb/ft^3
- Heat capacity - 0.83 Btu/lb-°F

Product specifications

- Moisture - 8-12% (10% av.)***
- Bulk density - 20 lb/ft^3
- Particle density - 42.4 lb/ft^3
- Heat capacity - 0.33 Btu/lb-°F

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*10% moisture basis.

**Baseline energy requirement for a rotary dryer was chosen as 9.533 million Btu's per ton of dry product (Baseline conditions - Table 6.4).

***Average value used in preliminary design.

be used to drive a heat pump compressor with little or no retrofitting, and that the "Magmamax" geothermal power system, as shown in Figure 6.4, was nearing commercialization. Calculations made using 300°F brine showed that at least 25 to 30 percent of the energy required for drying alfalfa with 75 percent initial moisture could be provided by this system.

- Case 3. Geothermal augmentation using a heat pump driven from a steam turbine: This concept, as shown in Figure 6.5, uses flashed steam to run the compressor and is similar to the power generation cycle used at the Geysers facility. Energy inputs to the drying cycle are similar to the preceding case.

- Case 4. Geothermal augmentation using a heat pump driven from a steam turbine and flashed geothermal steam in both the power cycle and heat-pump cycle: This system represents an attempt to reduce equipment costs, compared to Cases 2 and 3, by replacing all heat exchangers which contact the geothermal brine with flash vessels; it is shown in Figure 6.6. For a liquid-dominated resource, this is accomplished at the expense of increased brine flow. Energy inputs to the drying process would be the same as for Cases 2 and 3--25 to 30 percent.

- Case 5. Geothermal heat augmentation using a rotary steam-tube dryer: This design case represents an attempt to evaluate the merits of preheating the alfalfa feed rather than the dryer air, then using the conventional dryer to complete the dehydration. Preliminary evaluations suggest that a 300°F brine could be used in this manner to provide 30 to 35 percent of the energy required to dry alfalfa containing 75 percent moisture. This is sketched in Figure 6.7.

- Case 6. All-geothermal drying facility: Not an energy augmentation, this design case would rely on geothermal energy to provide all the energy for dehydration. The conventional rotary dryer would be replaced by a low-temperature dryer better adapted to the low-temperature geothermal resources. This case is shown in Figure 6.8.

The technical feasibility analysis of the six design cases for the Heber geothermal resource is presented in the remainder of this chapter.

Case 1. Geothermal energy augmentation using an air preheater: Figure 6.3 indicates this concept involves an air preheater ahead of a rotary dryer of conventional design, analogous to the heat exchanger now used at dehydration plants that practice exhaust-gas recirculation for energy conservation. The physical principle involved is relatively simple: since a major portion (95± percent) of the gas volume produced by natural gas combustion results from the combustion air, energy used to preheat the combustion air subtracts from the total natural gas requirement on a nearly 1:1 basis. Since the concept involved is simple and has been effectively demonstrated on plants employing gas recirculation, technical feasibility has already been demonstrated, except for detailed heat-exchanger design for large-scale implementation.

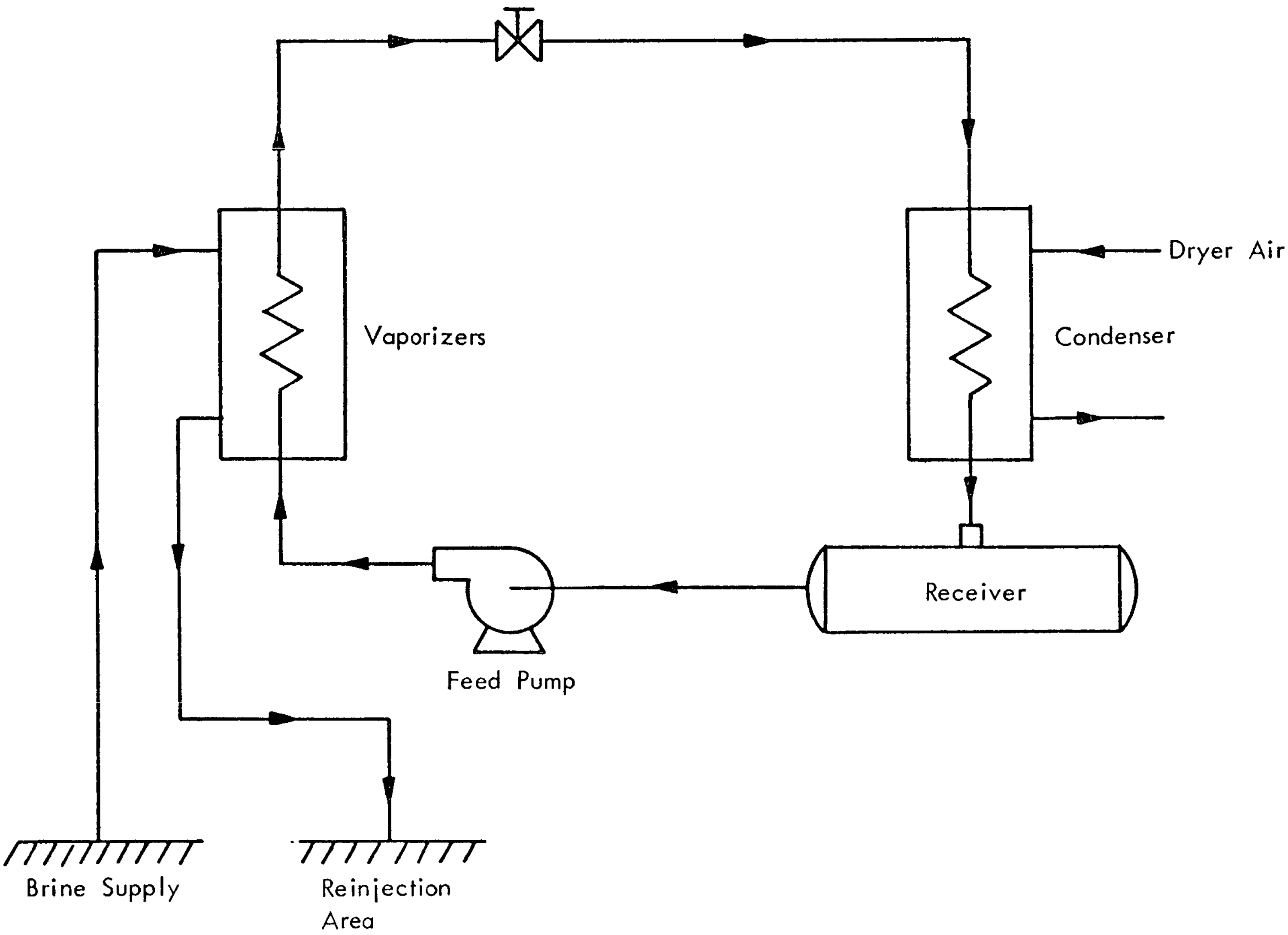

Figure 6.3. Case 1: Geothermal Augmentation Design Using Simple Air Preheater.

It was initially believed that, because of the corrosiveness of the geothermal brines, an intermediate working fluid should be used to reduce the size of the (more expensive) brine heat exchanger as depicted in Figure 6.3. Isobutane was initially selected as the intermediate working fluid. However, in practice the high pressures required to liquify the working fluid at brine temperatures result in a cost for the secondary heat exchanger comparable to a brine-to-air exchanger for the Heber brines ($15 to 20/$ft^2$).[20] For less corrosive brines than Heber's, the use of a single heat exchanger would be far less expensive than use of a secondary fluid.

A preliminary design summary for Case 1 is presented in Table 6.6. The inlet brine flow for a dryer capacity of 6.0 dry tons/hr and 75 percent initial moisture is 781 lb/min at 300°F. Air-flow rate is 4465 lb-moles/min. The heat exchanger is a fin-tube design with brine flow tube-side. The ratio of external surface to bare-tube surface is 20.1/1. The brine-flow rate is 4.42 ft/sec. The total heat duty is 6.6 million Btu's/hr and total external tube area is 7050 ft^2. The cost of the exchanger in 304 SS is $105,700 (FOB). The installed cost estimate shown in Table 6.6 is $212,000 to allow for transportation, foundation, installation, ductwork, fans, wiring and controls.

Case 2. Geothermal augmentation using Magmamax power cycle coupled to heat pump: Preliminary investigations disclosed that while a large-capacity heat pump per se is not commercially available, there is little practical difference whether the conventional Rankine cycle is used to drive an electric generator or a compressor, as required for the heat pump. An extensive bibliography of methods for low-level waste-heat recovery was found based on alternative uses of the turbine power developed in the basic power cycle.[21,22,23] Review of the literature on geothermal energy systems[24,25] and conversations with York Division of Borg-Warner disclosed that (a) the isobutane power system, which does not require a vapor-dominated geothermal source, was nearing commercial demonstration as the Magmamax process; (b) the Magma Energy Company of Los Angeles, which holds the patent rights, was willing to cooperate in making their technology available for license; and (c) a consulting firm was found which had previously evaluated the adaption of heat-pump technology to the Magmamax process. The first heat-pump system evaluated was based on this process.

Preliminary design calculations disclosed that, at a compression ratio of 10 to 1, using steam as the secondary working fluid, a 300°F brine could provide at least 21 percent of the heat input to a conventional rotary dryer. An additional 6-percent energy reduction could be realized by using the dryer air for intercooling between compression stages. The adaptation of the Magmamax process for agricultural drying processes is depicted in Figure 6.4.

The isobutane loop includes a vaporizer, which consists of a large bank of heat exchangers and is the primary brine heat exchanger; expansion valve; turbine; condenser; receiver; feed pumps; and closed cooling tower. A superheater, shown in Figure 6.4, was evaluated as a means of using the natural gas to increase the Rankine cycle efficiency, rather than as a dryer fuel, but the energy trade-offs involved proved unfavorable.

Table 6.6

AIR PREHEATER (CASE 1) PRELIMINARY DESIGN SUMMARY

Design capacity[a]	
Alfalfa "green chop" (75% moisture)	21.6 tons/hour
Alfalfa "dehy" (10% moisture)	6.0 tons/hour
Energy inputs (net)	
Natural gas	50.6 million Btu's/hour
Brine (300°F)	6.6 million Btu's/hour
Fuel savings	11.5%
Brine requirements	
Flow	781 pounds/minute
Energy (gross)	6.6 million Btu's/hour
Temperature	
Inlet	300°F
Return	160°F[b]
Pressure	
Inlet	90-100 psia[c]
Return	20 psia[d]
Dryer air requirements	
Flow	2,042 pounds/minute
Temperature	
Exchanger inlet	70°F
Exchanger outlet	180°F
Pressure	
Exchanger inlet	15.1 psia[e]
Exchanger outlet	14.7 psia
Equipment costs (installed)	$212,000

a Equivalent to capacity of two rotary drums of conventional design, e.g., Heil SF105-32 or equivalent.

b Assumed minimum return temperature.[18]

c Assuming pressure drop of 10 psia through brine side of exchanger.

d 20 psia nominal return pressure (assumed).

e Based on assumed flow resistance of 4 to 10 in wc. through heat exchanger.

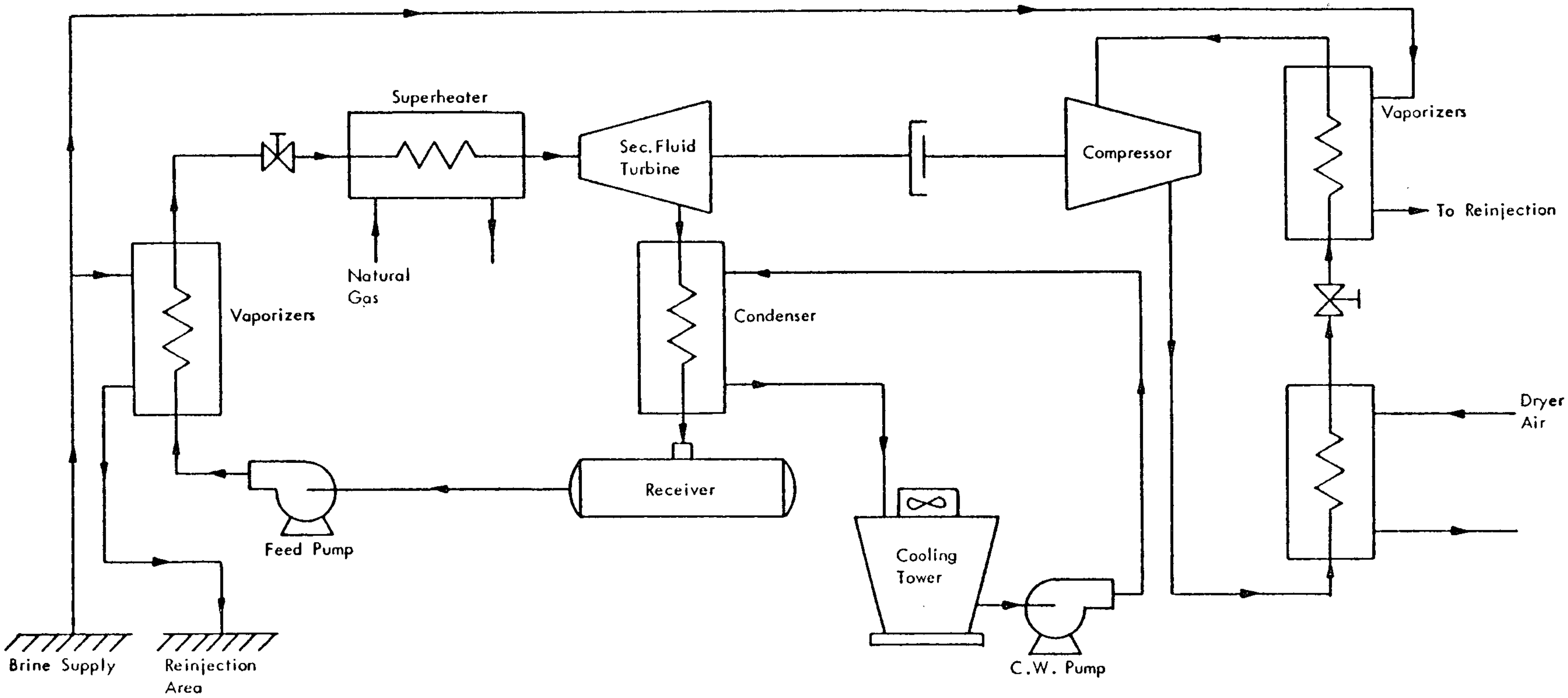

Figure 6.4. Case 2: Geothermal Augmentation with Heat Pump: Isobutane Turbine and Heat Pump Circuits.

For a 300°F brine supply, the theoretical Carnot efficiency of the Rankine (isobutane) cycle is 26 percent, although the ideal efficiencies of both steam and organic working fluids drop to about 20 to 22 percent.[22] Net cycle efficiencies for organic working fluids range from about 9.1 to 12.6 percent as shown in Table 6.7. Major advantages of using organic fluids rather than steam as the working fluid are (a) a superheater is not required; (b) turbine costs are lower for fluids having molecular weights greater than 1 atmosphere because the turbine can be smaller. The working fluid used in the Magmamax process is i-butane. A design efficiency of 12 percent was used which is somewhat conservative compared with the 12.24 percent given in Table 6.7.

Turbine power from the Magmamax power cycle is used to drive a compressor which serves as the basis of the heat-pump cycle in Figure 6.4. Steam was chosen as the working fluid for the heat-pump cycle, which includes a vaporizer, throttle valve, and a condenser which interfaces with the drying process as the air heat exchanger. A small portion of the total brine supply (about 5 percent) would be used to vaporize the steam ahead of the compressor. Other working fluids were not evaluated since the ideal coefficient of performance (COP) for steam (4.15) was comparable to the Carnot COP of 4.80, for a compression ratio of 10:1. A previous study of heat-pump performance under comparable conditions concluded that steam was the most effective working fluid among a number of candidate fluids evaluated that included n-hexane, i-pentane, n-octane, and Freon R-113.[25]

The actual coefficient of performance for the heat-pump cycle including system losses is estimated to be 2.01, which results in an overall cycle energy efficiency of slightly greater than 8.0 percent. If part of the energy potentially lost in intercooling between compressor stages is recovered by means of additional heat exchangers in which dryer air is preheated, overall cycle efficiency increases to 9.6 percent. The latter figure was used for sizing purposes.

Table 6.8 presents a summary of preliminary design data for the Magmamax heat-pump, geothermal-augmentation process. Baseline production rate is 6.0 dry tons/hr. Brine at 300°F would be used to provide 27.0 percent of total dryer energy requirements. Total brine-flow rate is 28,500 lb/min. Equipment costs are: $1,500,000 for the basic Magmamax turbine system (installed) with an additional $1,530,000 estimated for the heat-pump compressor, air preheater (steam condenser) and stage-intercooling heat exchangers. The compressor cost was the major auxiliary cost item with compressor power requirements estimated, using standard design procedures, to be 2026 hp.[26] Magmamax cost data was estimated for Heber brine conditions from information provided by the designer.[20] the basis used for the Magmamax power system was on the low side of the designer's estimate, which indicated that total installed cost could be greater by as much as 50 percent.[20]

<u>Case 3. Geothermal augmentation using a heat pump with geothermal steam as the working fluid in the Rankine power cycle</u>: Case 3, depicted in Figure 6.5, represents the first of two design cases evaluated (Cases 3 and 4) in which it was attempted to reduce heat-pump system costs by replacing one or both of the brine heat exchangers (in Case 2) by a simple flash

Table 6.7

EFFICIENCY PREDICTIONS FOR RANKINE CYCLE SYSTEM USING AN INTERMEDIATE ORGANIC WORKING FLUID (300°F BRINE)[24]

SECONDARY FLUID	TURBINE INLET PRESSURE-PSIA	NET CYCLE EFFICIENCY -%*
1. n-butane	500	12.61
2. $CHCIF_2$	1,100	12.40
3. i-butane	600	12.24
4. $C_2H_3CIF_2$	600	12.18
5. CCI_2F_2	700	11.89
6. $C_2CI_2F_4$	500	11.63
7. CCI_2F_2-$C_2H_4F_2$	900	11.25
8. propylene	900	10.96
9. ammonia	850	10.62
10. propane	900	10.47
11. C_2CIF_5	900	9.10

*NET CYCLE EFFICIENCY =

$$\left(\frac{\text{GROSS POWER OUTPUT - CYCLE PUMP POWER REQUIREMENTS}}{\text{VAPORIZER DUTY}}\right) \times 100$$

Table 6.8

ISOBUTANE HEAT PUMP SYSTEM (CASE 2)
PRELIMINARY DESIGN SUMMARY

Design capacity[a]	
Alfalfa "green chop" (75% moisture)	21.6 tons/hour
Alfalfa "dehy" (10% moisture)	6.0 tons/hour
Evaporative capacity (actual)	31,200 pounds/hour
Energy inputs (net)	
Natural gas	41.8 million Btu's/hour
Brine	15.4 million Btu's/hour[b,c]
Fuel savings	27.0%
Brine requirements	
Flow	28,500 pounds/minute
Energy (gross)	237.6 million Btu's/hour[d]
Temperature	
Inlet	300°F
Return	205°F
Pressure	
Inlet	100 psia[e]
Return	20 psia[f]
Dryer air flow requirements	
Flow	2,042 pounds/minute
Temperature	
Exchanger inlet	70°F
Exchanger outlet (dryer inlet)	583°F
Pressure	
Exchanger inlet	15.1 psia
Exchanger outlet	14.7 psia[g]
Equipment costs (installed)	$3,040,000[h]

a Selected design basis (representative of new capacity).

b Net heat input to dryer.

c Overall cycle efficiency assumed to be 9.6%.

d Reference temperature is 160°F (assumed minimum return temperature).

e Estimated value assuming pressure losses through primary heat exchanger are 15 to 20 psia.

f Nominal (assumed) return pressure.

g Based on assumed air flow resistance through heat exchanger of 4 to 10 in. wc.

h Cost estimate for Magmamax power cycle components from J. H. Andersen Associates 5/6/77;[20] cost estimates for compressor and air heat exchangers prepared from process data.

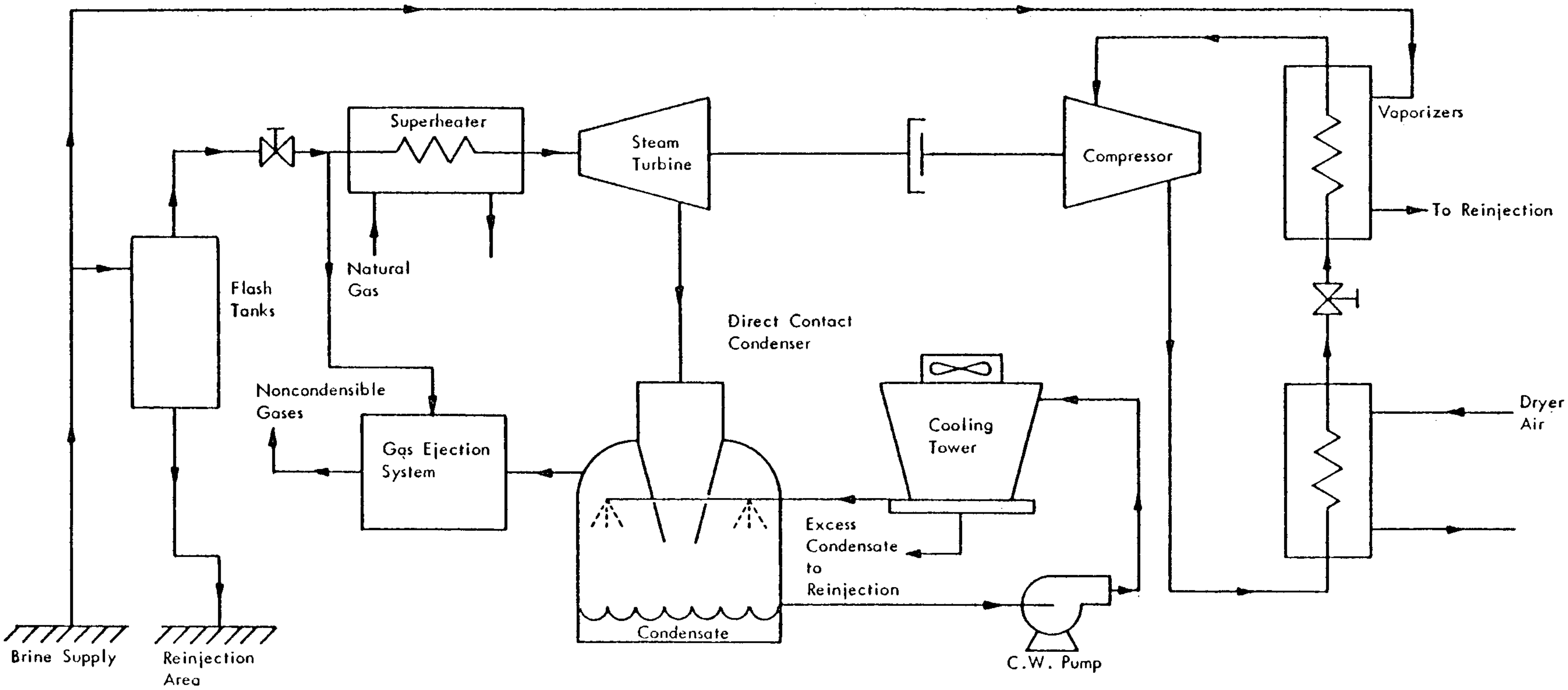

Figure 6.5. Case 3: Geothermal Augmentation with Heat Pump: Steam-Driven Turbine

system. Preliminary evaluation indicated that brine-flow requirements for Case 3 increased substantially compared to Case 2, while equipment costs were probably not substantially improved. In short, this system was not viewed as sufficiently promising for the Heber brine conditions to justify further evaluation.

Case 4. Geothermal augmentation using a heat pump with geothermal steam as the working fluid in an integrated Rankine power cycle/heat pump system: In the integrated heat-pump design shown in Figure 6.6, the brine heat exchangers are replaced by two flash systems. Pumping requirements, which are expected to contribute a significant portion of equipment costs in Case 2,[24] are also substantially reduced in this design. This is basically the geothermal heat-pump process proposed by Jensen and Neil,[25] in which steam from the first flash is used in the heat-pump cycle to heat the process air. Steam from a second flash system is expanded through a turbine (Rankine, or power cycle) and turbine power is used to drive the compressor. Although the basic thermodynamic limitations of the simplified heat-pump system are essentially the same as for Case 2, and overall expected cycle efficiencies are comparable, the use of the flash vessels results in considerably simplified equipment requirements. In addition, since the total steam enthalpy is utilized, slightly reduced brine-flow requirements are possible compared to Case 2, even though only the vapor portion of the brine is used directly.

Table 6.9 presents a summary of preliminary design results for the simplified heat-pump design based on the Heber geothermal resource (Case 4). Brine-flow requirement for a dryer capacity of 6.0 dry tons/hr and 75 percent initial moisture is 26,892 lb/min, which is 5.6 percent less than for Case 2. Brine-flow rates are considerably higher than estimated by Jensen and Neil for either of the two cases analyzed in their recent study.[25] Total equipment costs for this design case are estimated to be approximately $2,340,000 (installed). The installed-cost estimate was based on the Magmamax system costs with adjustment for heat exchangers and isobutane pumps not required in this design. The cost of the required flash vessels (entrainment separators) was estimated using standard design procedures.[26] As predicted by Jensen and Neil, additional costs for the entrainment separators were determined to be rather minimal by comparison with predicted costs for heat-transfer equipment; the estimated total installed costs for both separators at the vapor flows involved would be on the order of $50,000. The installed cost estimate shown in Table 6.9 is significantly higher, by at least a factor of 3, than Jensen and Neil's estimate of $224/kw,[25] although it is not clear whether these authors' estimate included installation and related costs.

Case 5. Geothermal augmentation using a rotary steam-tube predryer: Design Case 5 was chosen to investigate the feasibility of using the total geothermal brine flow in a steam-tube dryer of conventional design to partially dehydrate the alfalfa ahead of the conventional dryer, as depicted in Figure 6.7. This technique would be technically feasible for removal of at least 50 percent of the moisture (75 percent moisture basis), since this is essentially what is done in windrow drying alfalfa in the field as an energy conservation measure.[27]

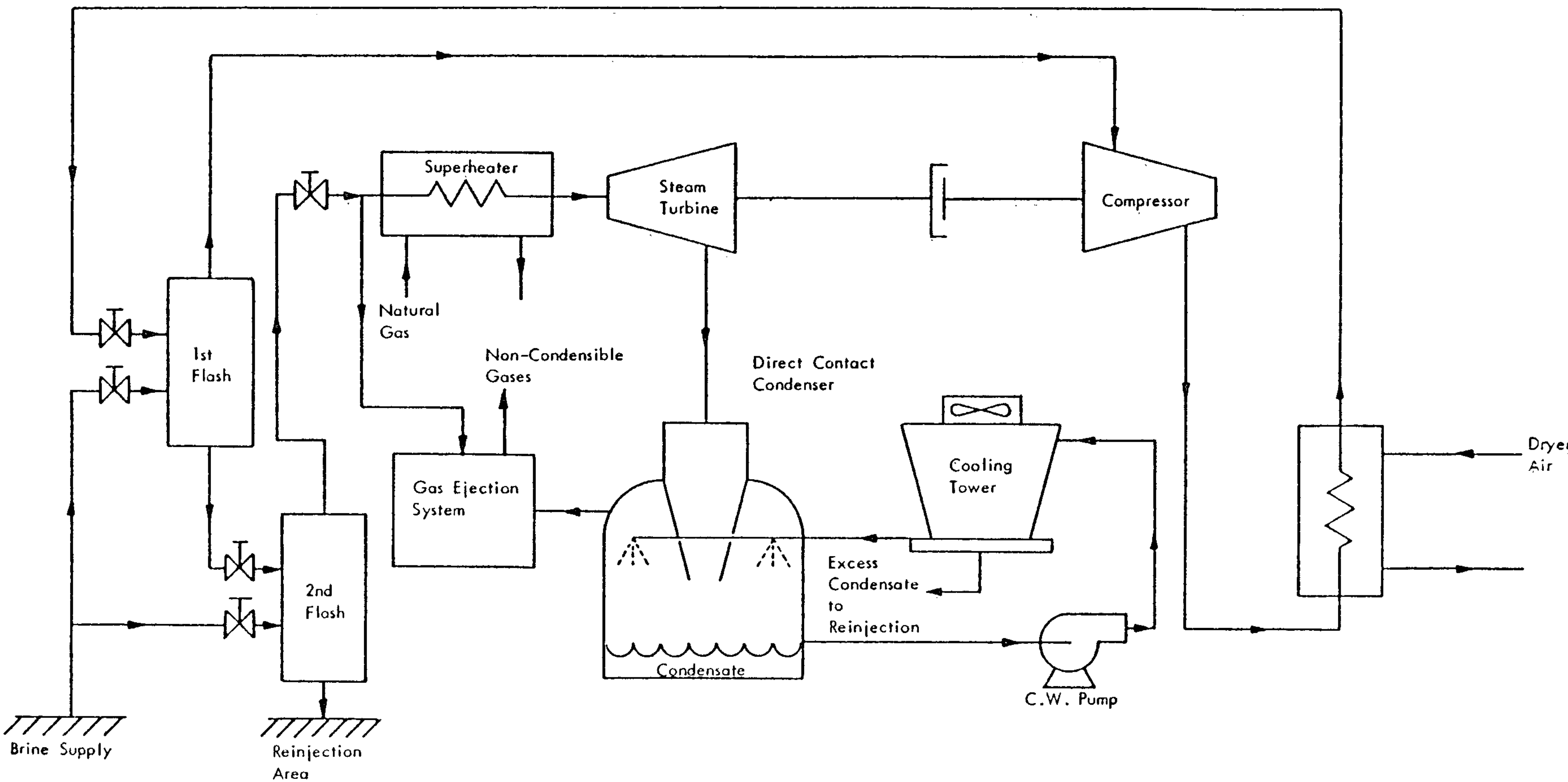

Figure 6.6. Case 4: Geothermal Augmentation with Heat Pump: Steam-Driven Turbine and Steam Heat Pump

Table 6.9

SIMPLIFIED HEAT PUMP (CASE 4) PRELIMINARY DESIGN SUMMARY

Design capacity[a]	
Alfalfa "green chop" (75% moisture)	21.6 tons/hour
Alfalfa "dehy" (10% moisture)	6.0 tons/hour
Energy inputs (net)	
Natural gas	43.35 million Btu's/hour
Brine	13.85 million Btu's/hour
Fuel savings	24.2%[b]
Brine requirements	
Flow	26,892 pounds/minute[c]
Energy (gross)	228.6 million Btu's/hour
Temperature	
Inlet	300°F
Return	160°F[d]
Pressure	
Inlet	80-85 psia[e]
Return	20 psia[f]
Air flow requirements	
Flow	2003 pounds/minute
Temperature	
Exchanger inlet	70°F[g]
Exchanger outlet	531°F[f]
Pressure	
Exchanger inlet	15.1 psia
Exchanger outlet	14.7 psia
Equipment costs (installed)	$2,340,000[h]

a Selected design basis considered representative of typical capacity addition.

b Maximum energy savings determined from the assumption that dryer air is used for interstage compressor cooling.[25]

c Determined from an overall cycle efficiency of 8.0%.

d Reference temperature is 160°F (assumed minimum return temperature).[18]

e Assuming pressure losses through heat exchanger (brine side) of 10.0 psig.

f Nominal return pressure.

g Assuming no intercooling is required between compressor stages.

h Estimate based on installed costs for Magmamax system.

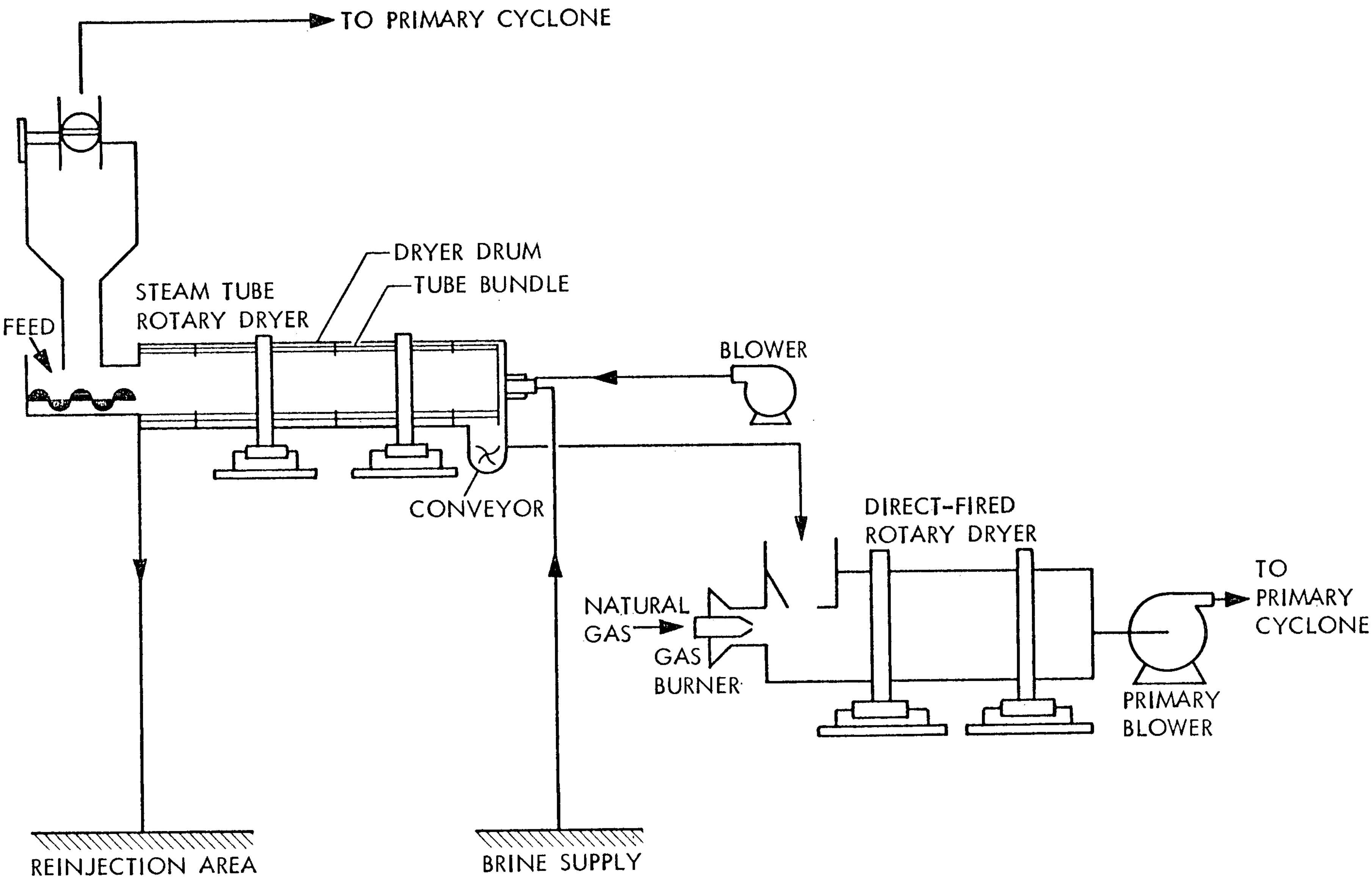

Figure 6.7. Case 5: Steam-Tube Predryer Coupled to Gas-Fired Drum Dryer

If the alfalfa were dehydrated in the predryer to perhaps 60 to 65 percent total moisture content, and drying completed in a gas-fired, conventional rotary dryer, then experience with drying "field wilt" alfalfa (60 to 65 percent moisture) indicates that an energy savings of from 39.6 to 45.9 percent could be realized. The drying of field-wilted, or low-moisture, alfalfa requires an adjustment of dryer conditions and net energy savings may be less than theoretical. In some parts of the country, drying of low-moisture, field-wilted alfalfa constitutes as much as 60 percent of total production yield.[13]

The steam-tube rotary dryer is used in applications in which the product is heat sensitive. Agricultural applications include the drying of brewer's grains.[2,10] Steam-tube dryers have a very high thermal efficiency;[12,16] the efficiency range is estimated to be 75 to 90 percent,[16] compared with an average efficiency for direct-fired rotary dryers used in alfalfa dehydration of about 60 percent.[2] Steam-tube rotary dryers reportedly are readily available in corrosion-resistant materials.[12] Since the total brine flow can be used in this drying system, brine use will be minimal. This concept seems well-suited to low-temperature geothermal resources.

A summary of preliminary design data for Case 5 is presented in Table 6.10. Use of the predryer will allow the increase of main dryer capacity by about 15 to 20 percent; however, for purposes of preliminary design, the same production rate was used as for the other design cases--6.0 tons/hr of dry product, 75 percent initial moisture content. A minimum natural gas savings of 33.4 percent is estimated for Case 5. Brine flow is significantly less than for Cases 2 and 4. Equipment costs, determined from Reference 16, are $320,000 for the rotary dryer, based on 304 SS believed necessary for the Heber brine (installed cost). Additional materials-handling equipment is necessary with this design option; costs for this equipment including in-feed conveyor, feeder, and lift apron are estimated to be about $51,400 (equipment only).[10]

Case 6. Low Temperature "Total Geothermal" Drying System: Case 6 involves the use of a low-temperature conveyor dryer using only geothermal energy for heat. The dryer depicted in Figure 6.8 is one of the many conveyor dryer designs commercially available; operation may be either co- or countercurrent, and the belt or conveyor may make one or multiple passes through the heated chamber. The conveyor dryer design is inherently well-suited for use with low-temperature geothermal resources; one manufacturer estimated that approximately 80 percent of all drying applications use air temperatures ranging from 250 to 300°F.[9] The efficiency of a low-temperature conveyor dryer can be comparable to that of a direct-fired rotary dryer (about 60 percent) when gas recirculation is practiced, i.e., there does not appear to be any fundamental reason why a lower drying temperature should result in a lower efficiency.[8] Longer residence times are required for this design than for conventional alfalfa dryers--about 30 to 45 min compared to 3 to 5 min in a conventional dryer.

Table 6.10

ROTARY PREDRYER (CASE 5) PRELIMINARY DESIGN SUMMARY

Design capacity[a]	
Alfalfa "green chop" (75% moisture)	21.6 tons/hour
Alfalfa "wilt" (60% moisture)	13.5 tons/hour
Alfalfa "dehy" (10% moisture)	6.0 tons/hour[b]
Energy input (net)	
Natural gas	38.1 million Btu's/hour[c]
Brine (300°F)	23.5 million Btu's/hour[d]
Fuel savings	33.4%
Brine requirements	
Flow	2,792 pounds/minute
Energy (gross)	23.5 million Btu's/hour[e]
Temperature	
Inlet	300°F
Return	160°F[e]
Pressure	
Inlet	100-110 psia[f]
Return	20 psia[f]
Equipment costs (installed)	$320,000[g]

a Selected design basis considered representative of typical capacity addition.

b No increase in capacity of direct-fired dryer was assumed to result from prewilting; limited data indicates approximately 15% increase may be feasible.

c Fuel used by direct-fired dryer.

d Heat required by steam-tube dryer based on an assumed thermal efficiency of 75%.

e Based on an assumed minimum temperature return of 160°F.

f Estimated from an assumed total system pressure drop of 24 psia.

g Estimated assuming 304 SS tubes;[16] additional equipment for materials handling estimated to cost $51,400 (FOB).

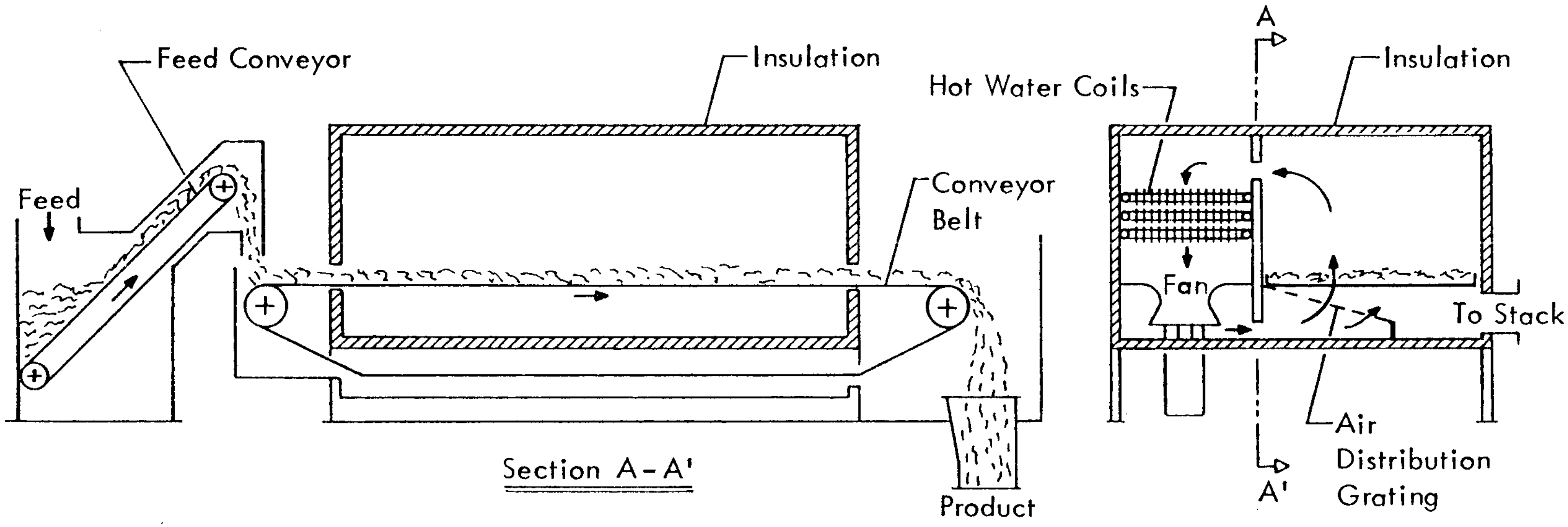

Figure 6.8. Schematic of Proctor & Schwartz Conveyor Dryer

Conveyor dryers were used previously in this country for alfalfa dehydration.[8] The reason for the demise of this system is not clear, although earlier designs were of relatively small capacity. Operating and maintenance costs may also have been a factor.

The technical feasibility of the concept of using geothermal fluids for alfalfa dehydration has been demonstrated in a commercial facility near the Broadlands field in New Zealand. This is a relatively small-capacity plant with a total capacity of 1.0 dry tons/hr. The geothermal fluid (steam at 350°F and 150 psi) is used to heat the dryer air (42,000 to 50,000 acfm) to 200 to 290°F in a coil heat exchanger. (See detailed description at the end of this chapter.)

There are some technical problems in adapting the Broadlands concept to large-scale dehydration using liquid-dominated, low-temperature geothermal resources. Although the fluid phase is not a direct factor, geothermal brines at Heber KGRA and elsewhere tend to be more corrosive than dry steam, so that attention must be given to materials of construction. Heber brine conditions are less severe than most locations within the Imperial Valley: for low pressure applications, type 304 stainless steel will probably be acceptable if design provisions are made for periodic equipment cleaning to remove scale, and fluid velocities are carefully controlled. Depending on design, titanium or titanium alloy may be required for some applications. Heat-exchanger size requirements will also increase for the lower-temperature resource. For a decrease in fluid temperature from 350 to 300°F, an increase in heat-transfer surface of about 70 percent is required, assuming constant inlet-air, dryer-air, and brine-return temperatures. Large-scale conveyor dryers are readily available from at least one major equipment supplier in this country. The manufacturer (Procter & Schwartz) estimated that development costs to determine the optimum size reduction and conveyor depth would add perhaps $15,000 to the total cost of the low-temperature dryer.

A preliminary design summary is presented in Table 6.11. For the baseline design capacity of 6.0 tons of dry product per hour, approximately 64.8 million Btu's/hr would be required, based on the manufacturer's estimate of 2000 Btu's/lb of water evaporated. (This efficiency [57.2 percent] is only slightly lower than for the rotary dryer fired with natural gas.) The dryer would comprise two separate units operated in parallel. For an evaporation rate of 8.1 tons/hr (H_2O), and based on a geothermal-fluid temperature of 250 to 300°F, the estimated size of each dryer would be 1100 ft^2 of drying area, requiring a length of 98 ft and a width of 12 ft.[17] A dryer this size is commercially available as Procter Conveyor Dryer Model SCF (Proctor & Schwartz, Inc., Philadelphia, PA). Brine and air-flow requirements were based on a dryer-recirculation rate of 60 percent, which would yield a discharge temperature of 160 to 170°F.[9] Dryer-air recirculation is required for high drying efficiency. Preliminary heat exchanger design is based on a fin-tube design with six separate units connected in parallel flow paths of three exchangers each. Each unit would consist of a bank of 1-inch tubes 30 ft in length. Total external surface for a 300°F brine, 280°F air temperature, and conditions shown in Table 6.11 would be approximately 418,600 ft^2.

Table 6.11

LOW-TEMPERATURE DRYER SYSTEM (CASE 6) PRELIMINARY DESIGN SUMMARY

Design capacity	
Alfalfa "green chop" (75% moisture)	21.6 tons/hour[a]
Alfalfa "dehy" (10% moisture)	6.0 tons/hour[a]
Actual Evaporative Capacity (H_2O)	31,200 pounds/hour
Heat requirements	64.8 million Btu's/hour[b]
Brine requirements	
Flow	7,714 pounds/minute
Gross energy input	64.8 million Btu's/hour[c]
Temperature	
Inlet	300°F
Return	160°F
Pressure	
Inlet	100-110 psia[d]
Return	20 psia[d]
Air flow requirements	
Flow	20,040 pounds/minute[b]
Temperature	
Exchanger inlet	70°F
Dryer inlet	280°F
Dryer outlet	160°F
Pressure	
Exchanger inlet	15.1 psia[e]
Dryer inlet	14.8 psia
Dryer outlet	14.7 psia
Cost (installed)	$1,650,000[f]

a Selected design basis considered representative of new capacity addition in the alfalfa dehydration industry.

b Determined from manufacturer's estimate for 280°F dryer air, 60% recirculation, 160°F discharge temperature[17]

c Based on reference temperature of 160°F (minimum return temperature).

d Based on vendor estimate of 24 psig pressure drop through primary heat exchanger. Twenty psia nominal return pressure.

e Based on vendor estimate of 2 in WC ΔP through heat exchanger plus estimated 7 in WC ΔP through dryer.

f Cost estimate for type 304 ss heat exchanger.

The multiple-exchanger configuration was believed necessary in order to allow for individual units to be taken off line, as necessary, for cleaning. The maximum rate of hard (silica) scale accumulation in the Imperial Valley is approximately one-eighth inch/year.[19] Since the solids concentration at Heber is less than average for the Imperial Valley brines, frequent cleaning should not be required.

A preliminary estimate of the cost of retrofitting a dehydrating plant with a 6-tons/hr geothermal conveyor dryer is about $1.65 million. This figure includes $474,830, the manufacturers FOB quote, for two Proctor Model SCF dryers with air recirculation; a like amount for dryer installation; an estimated $348,000 for the heat exchangers; and the same amount for heat-exchanger installation. Installation costs should be regarded as rough estimates. A lower capital cost, about $1.3 million, would result if dryers without air recirculation were substituted. However, a larger brine flow would be required in this case; the larger brine flow appears to be less cost effective than the higher initial expenditure for dryers with air recirculation.

Impact of Proposed Designs on Plant Economics

The approach taken in the preliminary economic screening of proposed design cases was to determine the additional costs required for retrofitting an existing plant to use the geothermal resource. Cost factors considered included equipment costs, brine costs, and other energy requirements as well as the additional manpower required for a facility operator to use 300°F geothermal brine to furnish part or all of his energy requirements. Results of this analysis are summarized in Table 6.12 and are discussed briefly in this section. Analytical methods used here are intended primarily as a first screening tool to differentiate between alternative designs. More detailed economic analysis, including a resource description and production cost breakdown specific to the Heber site will be presented in Chapter 9.

The preliminary analysis was based on the following assumptions:

- Production capacity was assumed to be 6.0 dry tons/hr, based on 75 percent initial moisture, and other conditions as specified earlier. Corresponding to this dryer capacity, annual capacity is approximately 16,000 tons based on production statistics compiled by the American Dehydrations Association.[4] In the Imperial Valley, the growing season for alfalfa is considerably longer than the national average, so for the purposes of preliminary economic evaluation, the selected annual production basis was 32,000 tons (60 percent capacity).

- The pre-retrofit fuel was assumed to be natural gas. Energy cost was assumed to be $1.50/million Btu's ($1.50 per thousand scf).

Table 6.12

PRELIMINARY ECONOMIC ANALYSIS OF DESIGN CASES 1 THROUGH 6

Design description	Case 1 Simple Air Preheater	Case 2 Magamax/ Heat-Pump Air Preheater	Case 3 Flashed-Steam Heat-Pump Air Preheater	Case 4 Flashed-Steam Heat-Pump Air Preheater (integrated Rankine, heat-pump cycles)	Case 5 Steam-Tube Rotary Predryer	Case 6 Conveyor Dryer
Fossil energy reduction	11.5%	27.0%	N.D.[a]	24.2%	33.4%	100%
Additional investment (January 1977)	$212,000	$3,040,000		$2,340,000	$320,000	$1,650,000
Operating costs (annual basis)						
Brine (300°F) at $2.50/million Btu's	$88,000	$3,168,000		$3,048,000	$313,300	$864,000
Electricity at $0.02/kwh	1,900	12,000		15,300	51,500	110,400[d]
Natural Gas at $1.50/million Btu's	(52,800)[b]	(123,300)[b]		(110,800)[b]	(188,000)[b]	(457,600)[b]
Electricity at $0.02/kwh	0	0		0	0	(12,800)[g]
Maintenance	6,000[h]	35,900		23,400	32,000	50,000[e]
Supervision (7% maintenance)	400	2,500		1,600	2,200	3,500
Taxes, insurance, G&A (4% inv.)	8,500	121,600		93,600	12,800	66,000
Total additional operating costs	$52,000	$3,216,700		$3,071,000	$223,800	$623,500
Capital recovery factor (0.1315)[c]	27,900	399,760		307,710	42,080	217,000
Total additional annual costs	$79,900	$3,616,460		$3,378,810	$265,880	$840,500
Additional cost per ton product[f]	$2.50	$113.01		$105.59	$8.31	$26.27

[a] Eliminated on the basis of preliminary technical feasibility analysis.
[b] Cost savings resulting from decrease in fossil energy consumption.
[c] Based on an assumed 15-year loan at 10% interest.
[d] Estimated from information given in Chilton.
[e] Heat-exchanger maintenance-cost estimate includes $17,700 for cleaning tubes plus 1% of H.E. capital cost ($348,000) for a total of $21,180; dryer maintenance estimated at 5% of dryer capital cost ($475,000), or $23,750.
[f] 32,000 tons/yr assumed.
[g] Cost savings resulting from decrease in electricity consumption, assuming 20 kwh/ton is required to run rotary-drum motors.
[h] Twice-a-year cleaning of heat-exchanger tubes.

- Brine cost at the plant battery limit was assumed to be \$2.50/million Btu's. Brine cost was considered to be independent of the rate of use. Brine properties were assumed to be those given in Table 9.2, except with a constant temperature of 300°F; no economic credit was taken for the unused energy between 205° and 160° in Case 2.

- Electrical energy requirement for blowers and auxiliaries was estimated from the maximum expected volumetric flow rates and pressure drops using standard design methods. Power requirement for drying equipment was estimated from a method given in Reference 16 for equipment of this type.

- Maintenance costs for heat exchangers and auxiliaries were estimated to be 1 percent of investment cost[28] plus labor for physically cleaning the tubes two times a year. Cleaning costs were based on a rate of 6 tubes/hr and a labor cost of \$20/hr. Maintenance cost for drying equipment may be as high as 10 percent/year.[16] The expected maintenance cost factor (or range) depended on the type of drying equipment under consideration.

- Maintenance supervision costs were assumed to be 7 percent of total maintenance costs.

- Taxes, insurance, and G&A (general and administrative expenses) were assumed to be 4 percent of the total new equipment investment.

- A capital recovery factor of 0.1315 was used, based on an assumed 15 year loan at 10 percent interest. No investment tax credit was assumed. If government-secured or municipal funding could be obtained, the capital investment penalty would be substantially less than that shown in Table 6.12.

As shown in Table 6.12, the additional cost per ton of dehydrated alfalfa associated with the use of geothermal energy ranged from \$2.50 for the air preheater (Case 1) to \$113 for the Magmamax heat pump (Case 2). The additional cost for using an auxiliary dryer heated with geothermal brine (Case 5) would be about \$8.31/ton. The unit cost increment for the low-temperature dryer (Case 6) would be about \$26.27 per ton (product basis).

Fuel costs for alfalfa dehydration have increased significantly from about \$4.05/ton in 1970[29] to \$15 to 20/ton at today's fuel prices. While none of the design cases would achieve a net reduction in production costs, the maximum allowable incremental cost for a 15-year assumed plant life would be \$11 to 16/ton, assuming a linear growth rate in fuel prices. On the basis of this preliminary analysis, use of either an air preheater (Case 1) or a predryer (Case 5) would appear to be feasible, while use of heat pumps (Cases 2, 3, and 4) would appear to be clearly infeasible. Use of a conveyor dryer may be viable, although site-specific analysis is required to determine economic feasibility (see Chapter 9).

The New Zealand Case.

Design Case 6 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 the study team by Mr. Ken Pirie of Fisher and Paykel Engineering Company, designer of the plant.[30]

The plant, located about 35 miles 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 100 feet long, composed of two 50-foot sections 8 feet 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 15 inches deep.

The heat exchanger is a steel fin-tube type, a coil eight rows deep, galvanized on the outside, 5 fins/inch. A total of 15,000 square feet of surface area is used. This was thought to be 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 350°C. The pressure is constant at 150 pounds per square inch. Ambient air (60 to 80°F) is passed over the coil and heated to 200 to 290°F. Air-flow rate is variable from 42,000 to 50,000 cubic feet per minute to permit different initial moisture contents in the alfalfa input. The inlet moisture of the alfalfa varies from 65 to 80 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 ranged from 8 to 12 percent and usually is about 10 percent. Outlet air temperature is 120°F dry bulb, 90°F wet bulb. Alfalfa throughput is about 1 ton/hour on a dry weight basis (5 tons/hour wet basis). Annual production is 1800 tons dry pellets, but much more is possible.

An analysis of the dehy product from the Broadlands plant shows product quality comparable with that currently standard in the Western United States, despite a drying time of approximately 30 to 45 minutes. (Retention time in a conventional drum dryer is two or three minutes.)

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CHAPTER 7: A MODEL OF THE DRYING PROCESS

Introduction

All of the cases described in the previous chapter involve new equipment either in the form of preheaters or completely new dryers. Recognizing the frail conditions of the alfalfa dehydration industry, we sought to identify means for using conventional-drum dryers with minimum modification in conjunction with geothermal fluids as an energy source. The New Zealand example serves to illustrate that drying temperature could be traded off against dwell time in the dryer; we sought to identify how conventional drum dryers could be used at lower operating temperatures than currently employed by the industry. In order to perform this aspect of the analysis, a computer model was constructed to investigate the thermodynamics and drying characteristics of grains and grasses subjected to varying drying temperatures for various lengths of time in a drum-dryer configuration.

The study team contacted the American Dehydrators Association early in the study to determine whether or not analytic methods determining the relationship between dryer air temperature and material dwell-time had been developed. In fact, such a model had been constructed by Air Resources, Inc.; and through the offices of the American Dehydrators Association, The Futures Group was able to obtain a copy of this model.

The computer model obtained by The Futures Group had undergone several significant modifications subsequent to its preparation by Air Resources, Inc. The basic physics and chemistry of the process as described by Air Resources had been retained, but a number of changes had been made in the way the numerical calculations were performed. The basic model as received proved less useful than had been hoped (because of lack of flexibility and internal errors). This model was extensively revised and streamlined with respect to both physics of the process and the numerical techniques employed to effect a solution. Additions to the model were made to simulate recirculation of a fraction of the dryer outlet gas and allow an estimate to be made of the loss in nutrients that can be expected during the dehydration process. Quantitative experimental data required to effectively utilize this latter feature of the program are extremely sparse, and meaningful conclusions may not be possible without additional test data.

The modified computer model was employed to examine a large number of variations in operating conditions and geometry of rotary-drum dryers. We found that rotary dryers operating at relatively low temperatures cannot provide enough throughput for reasonably economic alfalfa dehydrating operations. Nevertheless, this model should be quite valuable in the analysis of energy use for drying processes in applications other than alfalfa.

Model Design Concepts

The model as it currently exists is limited to an analysis of rotary-drum dryers. These dryers can be either single or triple pass, as described in Chapter 6, and can be of arbitrary diameter and length. In the program, the physical description of the dryer consists of specifying the drum length, one or more diameters associated with the drum depending on whether the dryer is a single- or triple-pass configuration, the height of the flights within the drum, the rotational rate of the drum, and the angle of repose associated with the material falling from the flights as the drum rotates.

The original model specified operating conditions for the dehydrator by specifying the rate at which natural gas was burned in heating the air, together with an initial temperature desired. The current model has been modified to provide a more natural description of the operating characteristics involving the throughput of dried material desired, the desired outlet temperature, and the volumetric gas flow at the outlet of the dehydrator. It was considered that this set of variables allowed more flexibility in parametrically examining the performance of this type of dryer. These parameters, generally speaking, are the ones that are under the control of an operator in a dehydration facility.

The physical description of the alfalfa as originally developed by Air Resources was retained. This description considers the particles to be dried to fall into one of three classes: stems, leaves, and shattered particles. These classes are described by combinations of geometries involving cylinders, flat plates, and spheres. The final description of the material entering the dehydrator separates the entering material into as many as four components, each of which is then described by one of the geometries just mentioned. Each class of particles is described by specifying its surface area, density, and the weight percent associated with each of the four components. A description of the material is completed by specifying the weight percent of water in each of the classes together with specific heats and the initial temperature.

Operating conditions for the dehydrator are input to the model by specifying the desired outlet temperature for the material and gas, the outlet fan speed in terms of the actual volume of gas moved per minute, and the dehydrated product throughput rate in terms of the weight of final product per hour of operation.

The program starts the calculation with the solution of an overall mass and energy balance. This solution provides the required inlet temperature and airflow requirements consistent with the desired throughput and outlet temperatures. Using these calculated inlet conditions, the program continues by doing a stepwise calculation down the length of the dehydrator drum. At each step in the calculation, values are obtained for the temperature, composition, and flow rate of the gas, the temperature for each component of the material being dried, the moisture content for each component of the material, the mean moisture content, and the residence time of each component of the material within the section of the drum being considered. In addition to these calculations, the program also solves a chemical decomposition rate equation that was introduced in an attempt to evaluate nutrient losses during the dehydration process. As mentioned in another portion of this report, data on nutrient loss in the alfalfa dehydration process were not considered to be adequate for an accurate simulation of this parameter. However, if such data become available in the future, the mechanism is built into the program to allow a rather flexible evaluation of nutrient loss based on temperature, moisture content and dwell-time within the dehydrator.

As an example of the output of the computer model, Table 7.1 shows the results of a calculation that simulates the behavior of the Heil SD-105-32 dehydrator operating under a set of conditions consistent with those identified in Chapter 6. As can be seen from Table 7.1, the conditions chosen for this particular calculation are somewhat lower than the maximum capacity quoted for this dehydrator. The dehydrated material throughput was taken as 6000 pounds per hour and the exit gas flow rate at 24,000 cubic feet per minute while the maximum capacity quoted is 6800 pounds per hour and a gas flow rate of 28,000 cubic feet per minute.

The numbers in the last column of Table 7.1 expressing the loss in "xanthophyll" should not be given a great deal of credence, although they are consistent with the numbers available from the limited experiments that have been performed and discussed in Chapter 8.

Several features of the calculation are best described by reference to the data in Table 7.1. The information at the top of the table is a combination of the input data specifying the performance requirements of the dehydrator and a solution to the overall energy and mass balances associated with the dehydration process. As can be seen from the table the requirements set for this particular calculation required that the inlet temperature be nearly 1600°F. The moisture content of the alfalfa at the inlet and the desired moisture content of the dehydrated product were taken as 75 percent and 10 percent respectively. The wet-bulb temperature associated with the inlet gas was calculated to be 162°F. The total water evaporated in the process was 15,600 pounds per hour. This required an inlet air flow of 53,400 pounds per hour and this calculation was done without any recycling. The theoretical amount of energy required to perform the dehydration process for the conditions specified in this case was calculated as 1310 Btu's per pound of water evaporated. This places an overall energy requirement of 20 million Btu's per hour on the energy source.

During the calculation of conditions in the drum it is initially assumed that all the heat transferred from the hot gas to the alfalfa particles goes into raising the temperature of the particles from their initial temperature to the wet-bulb temperature associated with the flowing gas. Water is then evaporated from these particles while their temperature is maintained at this wet-bulb temperature until the moisture content within each class of particles has reached a critical moisture content of 15 percent. At that point in the calculation it is assumed that the mechanism for water evaporation changes from one of simple evaporation of liquid at the surface to a process controlled by the diffusion of water from the interior of the particle to the outer surface. When the moisture content in each class of particles has reached this critical level, the temperature of the particle rises due to the fact that all of the energy transferred to the particle is not used

Table 7.1

EXAMPLE OF OUTPUT FROM MODEL

THIS IS CASE NUMBER 1.00 10/19/1977

INLET TEMPERATURE	1557 DEG F
NOMINAL OUTLET TEMPERATURE	260 DEG F
NOMINAL OUTLET GAS FLOW RATE	24000 ACFM
INITIAL MOISTURE CONTENT	75.0 o/o
FINAL MOISTURE CONTENT DESIRED	10.0 o/o
DRIED MATERIAL THROUGHPUT	6000 LB/HR
WET MATERIAL INPUT IS	21600 LB/HR
WET BULB TEMPERATURE	162 DEG F
WATER EVAPORATED	15600 LB/HR
RECYCLE RATIO	0.000
FLOW THROUGH HEATER	53406 LB/HR
INLET AIR FLOW	53406 LB/HR
	11106 SCFM
	12271 ACFM

ENERGY REQUIREMENT 1309 BTU/LB-H20 (20.43 MM BTU/HR)

X	TG	T1	T2	T3	T4	VEL	M1	M2	M3	M4	MEAN	LOSS(o/o)
0	1557	80	80	80	80	2503	75.0	75.0	75.0	75.0	75.0	0.0E+00
1	1491	111	124	149	162	2421	75.0	75.0	75.0	75.0	75.0	1.5E-05
2	1456	141	162	162	162	2380	75.0	75.0	75.0	74.0	75.0	2.5E-04
3	1397	162	162	162	162	2341	75.0	74.5	74.1	72.9	74.4	8.4E-04
4	1339	162	162	162	162	2304	74.6	73.9	73.2	71.7	73.7	1.5E-03
5	1283	162	162	162	162	2268	74.2	73.3	72.3	70.4	73.0	2.3E-03
7	1182	162	162	162	162	2199	73.5	72.1	70.3	67.6	71.5	3.7E-03
10	1051	162	162	162	162	2103	72.3	70.3	67.0	62.8	69.2	6.0E-03
14	908	162	162	162	162	1990	70.7	67.7	62.0	55.1	65.9	9.3E-03
19	769	162	162	162	162	1869	68.7	64.3	55.1	43.6	61.6	1.4E-02
24	660	162	162	162	162	1766	66.6	60.6	47.1	30.1	56.9	1.9E-02
29	574	162	162	162	162	1681	64.5	56.8	38.1	17.8	52.0	2.4E-02
30	554	162	162	162	162	1660	64.1	55.8	35.1	15.1	50.6	2.5E-02
31	533	162	162	162	328	1360	63.6	54.7	31.6	14.4	49.1	2.7E-02
33	499	162	162	162	335	1330	62.6	52.6	25.5	9.3	46.4	1.4E-01
36	460	162	162	162	394	1294	61.2	49.7	17.5	6.6	42.7	5.5E-01
39	427	162	162	311	423	1259	59.8	46.7	14.8	6.0	40.1	2.0
43	401	162	162	313	405	1235	58.1	42.9	11.5	4.4	36.9	4.3
47	379	162	162	332	388	1212	56.3	39.0	9.6	3.2	33.8	6.6
51	360	162	162	346	367	1194	54.6	35.1	8.9	2.4	31.1	10.5
55	345	162	162	348	351	1179	52.8	31.1	8.8	2.0	28.6	14.8
59	330	162	162	338	338	1163	51.0	27.0	6.6	2.0	25.6	18.0
60	324	162	162	332	331	1157	50.5	25.5	4.9	2.0	24.3	18.6
61	317	162	162	324	323	585	49.8	23.6	3.7	2.0	22.9	19.6
63	309	162	162	312	312	580	48.5	20.5	2.7	2.0	20.9	21.3
65	300	162	162	305	305	576	47.3	17.4	2.0	2.0	18.9	22.5
67	295	162	162	297	297	573	46.0	15.1	2.0	2.0	17.5	23.4
70	287	162	253	291	290	567	44.2	14.7	2.0	2.0	16.8	24.4
74	283	162	254	281	281	565	42.1	13.7	2.0	2.0	15.7	26.0
79	278	162	256	280	280	563	39.5	12.9	2.0	2.0	14.6	27.8
84	275	162	259	276	276	561	36.9	12.3	2.0	2.0	13.5	29.5
89	271	162	262	273	273	559	34.2	11.9	2.0	2.0	12.6	31.2
90	270	162	263	271	271	559	33.3	11.8	2.0	2.0	12.4	31.5

RESIDENCE TIMES

COMPONENT 1	3.4 MINUTES	(15.0 PERCENT)
COMPONENT 2	2.1 MINUTES	(43.0 PERCENT)
COMPONENT 3	1.4 MINUTES	(39.0 PERCENT)
COMPONENT 4	1.3 MINUTES	(3.0 PERCENT)

THE WEIGHTED MEAN RESIDENCE TIME IS 2.0 MINUTES

ENERGY USE EFFICIENCY 79.1 o/o (1323 BTU/LB-H20)
ACTUAL OUTLET GAS FLOW RATE 24262 ACFM

DRUM LENGTH	30.0 FT
INNER DIAMETER	4.8 FT
MIDDLE DIAMETER	7.2 FT
OUTER DIAMETER	10.3 FT
FLIGHT HEIGHT	.7 FT
ROTATION RATE	7.0 RPM

KEY TO TABLE 7.1

X	Location in feet measured from inlet (X = 1 to 30, first pass; X = 30 to 60, second pass; X = 30 to 90, third pass)
TG	Local gas temperature (degrees F)
T1, T2, T3, T4	Alfalfa temperatures (degrees F)
VEL	Local gas velocity (ft/min)
M1, M2, M3, M4	Alfalfa moisture content (%)
Mean	Mean moisture content (%)
Loss	Estimated xanthophyll loss (%)

in vaporizing water but a portion goes into changing the temperature of the particle as well. From that point on, the temperature of the particle remains very near that of the flowing gas and the moisture content continues to decrease until the end of the drum is reached. The last step in the calculation is an evaluation and printing of the residence time within the drum for each of the four components considered. The numbers in parentheses following the residence time are the weight percent of each of these components in the original feed material. As can be seen from Table 7.1 residence times for this calculation ranged from 1.3 minutes for the smaller, lighter, shattered leaves in the feed material to 3.4 minutes for the heavier and larger stems. This variation in residence time is due to the fact that the program assumes the mechanism for moving material through the dehydrating drum is the aerodynamic drag produced on the particles falling within the drum by the gas flowing through the drum. This has the effect of moving the smaller, lighter particles through the system at a higher velocity than the larger, more dense particles.

The model in its present configuration is written in the BASIC language and is operational on The Futures Group IBM 5100 computer. The program utilizes approximately 24K of computer memory and requires 10-15 minutes to perform the calculations for a typical dehydrator simulation.

Modeling Results

During the course of the study the model described in the preceding paragraphs was utilized to simulate a large number of cases involving variations on existing dehydration equipment currently used by the industry. Specific cases were examined to determine the feasibility of various combinations of energy sources utilizing geothermal resources as the basic energy supply for the dehydration process. In these cases it was generally assumed that the individual dehydration facilities would operate in a manner analogous to that in which they currently operate--namely, that a minimum product throughput of approximately 4000 pounds per hour was necessary and the facility would operate on alfalfa with initial moisture content averaging approximately 75 percent and the dehydrated product would have a final moisture content of approximately 10 percent. Some variations involving these basic assumptions were examined parametrically and will be discussed in a later paragraph. In general, the conclusion reached from simulations of existing dehydration equipment operating within the assumptions just stated is that no combination could be found that would allow an economically viable dehydration of alfalfa with the use of low-grade geothermal resources. These conclusions have been discussed in some detail in Chapter 6 of this report.

Using this model, it is possible to do large-scale parametric studies of the dehydration process not only for alfalfa but for other crops using rotary-drum dryers. Since a detailed examination of the physics and chemistry of the dehydration process was not a primary goal of the present study, only limited parametric variations were made.

Due to the very large number of parameters involved and their complex interaction, only a limited parametric examination of the dehydration process was deemed appropriate for the present study. In order to work within a realistic range of parameters associated with a dehydration facility, several ground rules were established prior to the parametric variations. Table 7.2 indicates the basic assumptions that were made. Rather than perform parametric variations on the rather complex triple-pass drum configuration, a simple single pass, ten-foot diameter drum was chosen to display the main features of the dehydration process. The rotation rate of the drum was held constant at 7 RPM and the throughput of dehydrated material was chosen as 4000 pounds per hour. The basic exit gas flow was taken as 25,000 ACFM. Parametric variations on this exit gas flow were made for some cases.

It is of interest to examine the minimum inlet temperature required to perform the dehydration process as a function of the total airflow through the dehydrator. This calculation is made by assuming that the gas emerging from the exit of the dehydration drum is completely saturated with water. The exit temperature is thus the wet-bulb temperature corresponding to the inlet gas. The results of this calculation then give the inlet temperature required for dehydrating the alfalfa in an infinitely long rotating drum. Figure 7.1 shows the results obtained from this type of calculation under the assumption that throughput is 4000 pounds of dehydrated material per hour. As can be seen from the figure, for the conditions chosen the minimum temperature required does not approach those temperatures of interest in the present study for the geothermal resource until very large values of airflow are reached. While this situation is not incompatible with conveyor type dryers as discussed in Chapter 6, it does present considerable problems with drum dryers of a practical size. For example, in the case of a fixed drum diameter, as the airflow through the drum is increased to these very large values the velocity of the gas through the drum also increases, thus reducing the retention time for the material in the drum. The interaction between the airflow requirements, the inlet temperature, and the overall drum length then becomes quite complex due to the fact that as the gas flow increases, the retention time is decreased thus requiring a longer length for a given final moisture content in the dehydrated product.

Table 7.2

BASIC ASSUMPTIONS

Drum Diameter	10	ft
Flight Height	1.5	ft
Rotation Rate	7	RPM
Exit Gas Flow	25,000	ACFM
Initial Moisture Content	75%	
Final Moisture Content	10%	
Throughput	4000	lb/hr

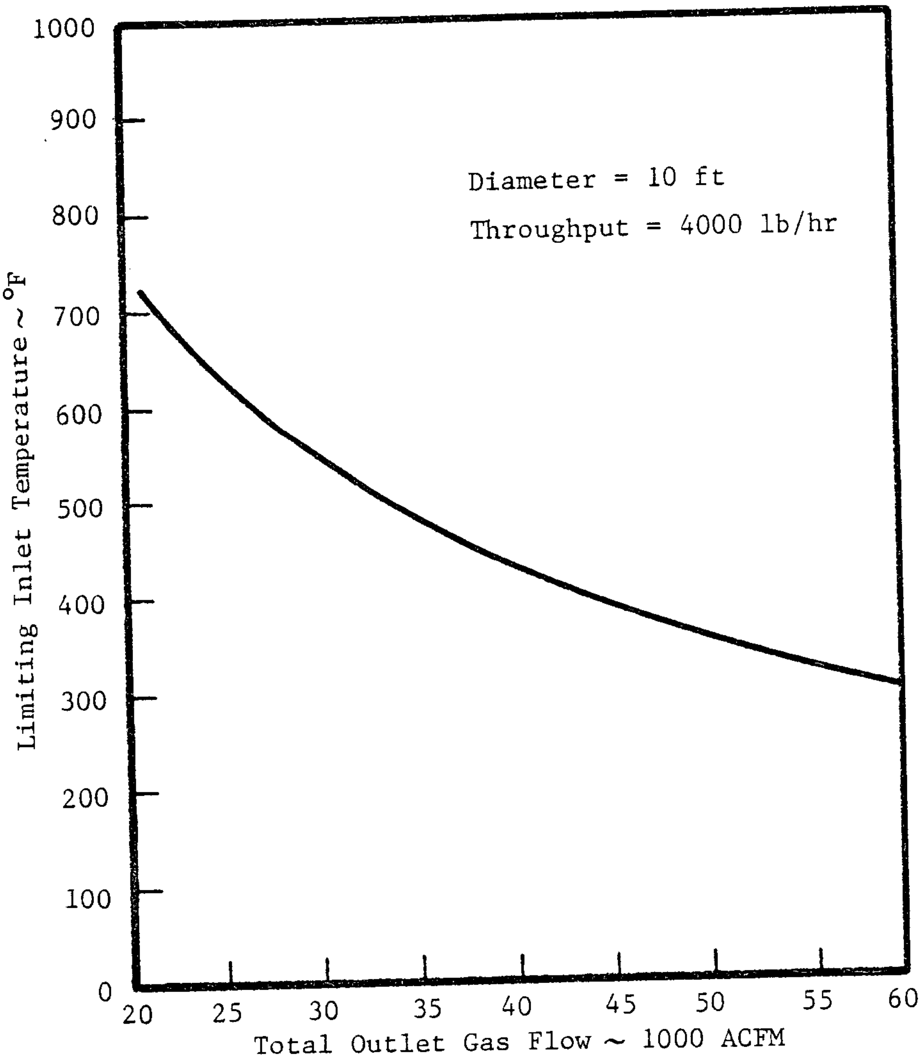

Figure 7.1. Theoretical Minimum Inlet Temperatures

One of the calculations that can readily be performed using the present model is a determination of the length of the drum required to perform a particular dehydration process as a function of the inlet temperature. Figure 7.2 displays the results of such a calculation in which the basic dehydrated material throughput was taken to be 4000 pounds per hour at an exit gas flow rate of 25,000 ACFM. Figure 7.2 clearly shows the dramatic increase in the required drum length as the inlet temperature decreases and approaches the limiting value, which in this case is approximately 680°F. Similar behavior is shown in Figure 7.3, which shows the calculated mean residence time of the alfalfa in the dehydration drum for the same set of cases. As can be seen from the figure, the time required to perform the dehydration process becomes quite long as the inlet temperature decreases. However, this increased dehydration time does not necessarily indicate an increased loss in nutrient quality for the dehydrated product. This is due to the fact that the increased time is accompanied by a decrease in the maximum temperature to which the material is exposed during the process. To the extent that the nutrient loss model represents reality, this is shown in Figure 7.4 where the calculated nutrient loss for this same set of dehydration cases is displayed as a function of the inlet temperature.

Among the large number of parameters associated with this problem, it is of particular interest to examine the behavior of dehydration systems as a function of the moisture content of the inlet material. Calculations were performed in which the inlet material moisture content was varied between 75 percent and 55 percent. The desired throughput of dehydrated material was maintained at 4000 pounds per hour and the total exit gas flow rate was maintained at 25,000 ACFM. The results of these calculations are shown in Figure 7.5. Two sets of calculations were performed. In one set of calculations the outlet temperature of the dehydrator drum was maintained at 200°F., and in the other set of calculations the inlet temperature to the dehydrator drum was fixed at 880°F. The effect of the initial moisture content on the drum length required for both sets of calculations is shown in Figure 7.5. As can be seen from the figure, in either case the required drum length is very sensitive to the initial moisture content. This result is not surprising since the decrease in moisture content from 75 percent to 55 percent represents a decrease of almost one half in the amount of water required to be evaporated from the material during the dehydration process. It is apparent from these considerations that any process that results in removal of water from the green material prior to dehydration represents a very significant saving in total energy utilization by the facility. As is discussed in Chapter 8, this process can be accomplished mechanically, by field-wilting, or by sun curing the material.

A second method of evaluating the effect of dewatering prior to dehydration is to examine the operating requirements of an existing dehydrator as the initial moisture content is decreased. A number of operating modes are available, and which of these is most attractive to a given operator is not known. Two of the possible modes are the following:

1. As the initial moisture content is decreased the exit gas flow and product throughput are held constant and the inlet and outlet temperatures are decreased to accommodate the lower moisture content.

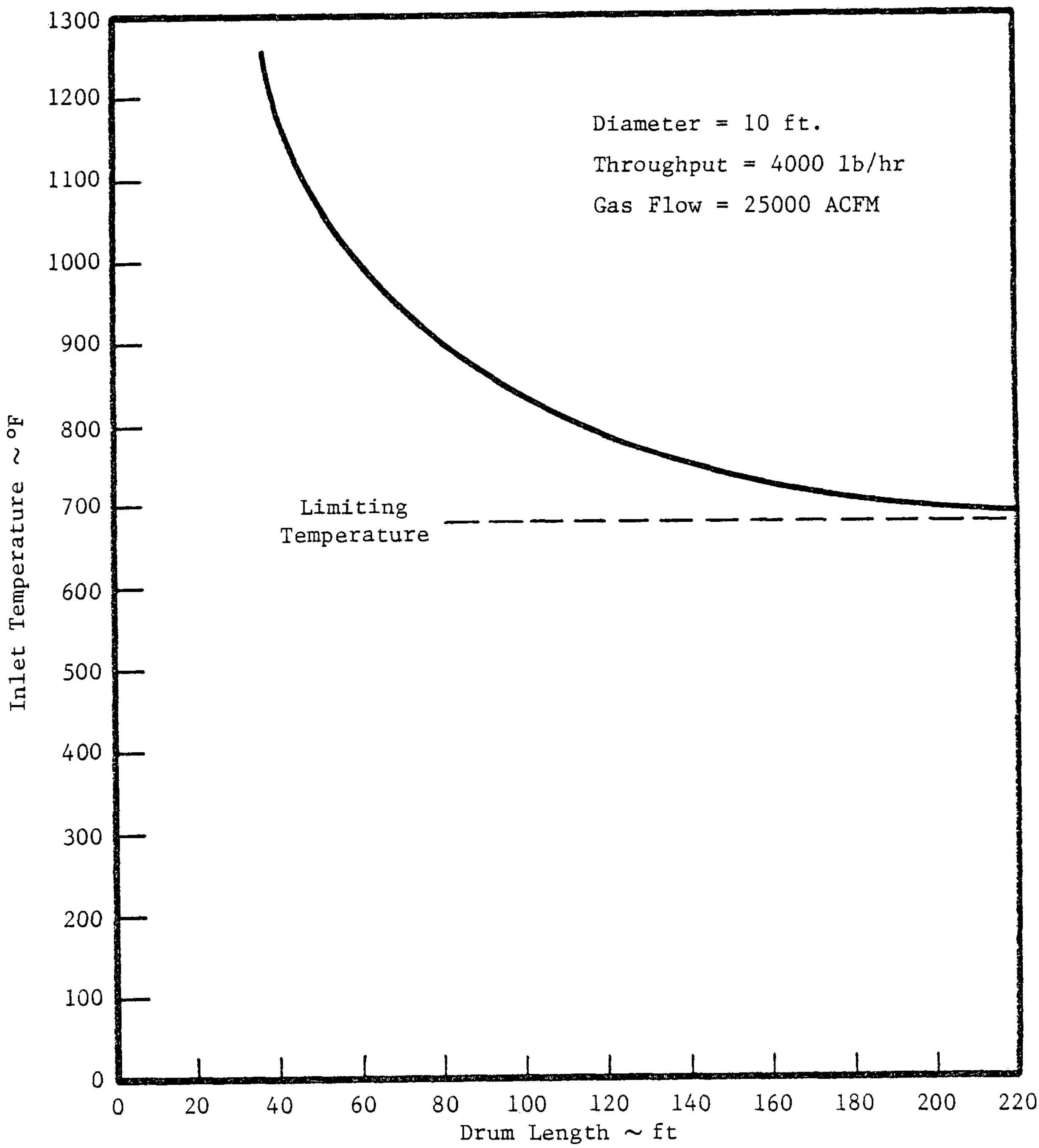

Figure 7.2. Effect of Inlet Temperature on Drum Length.

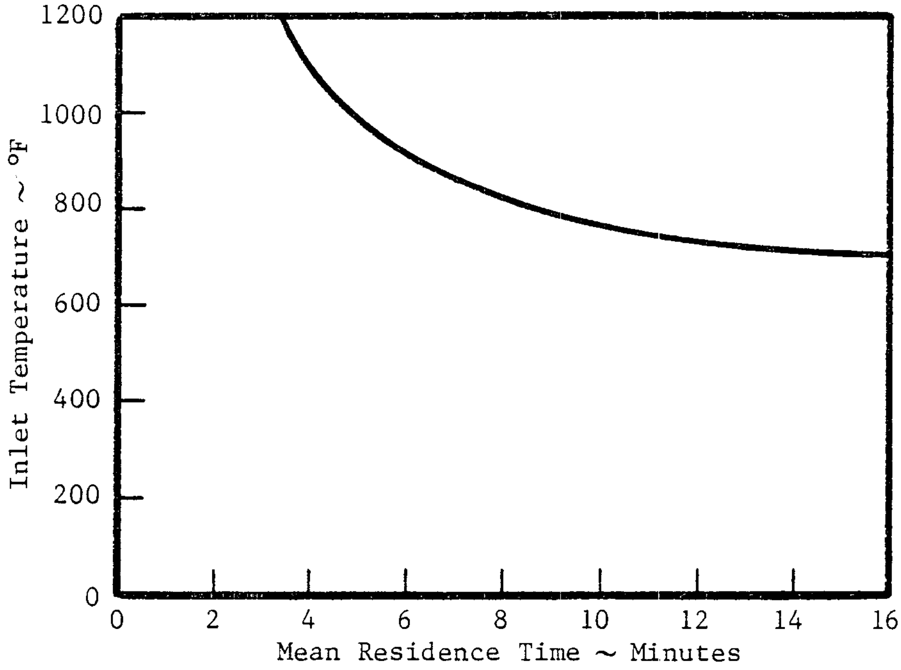

Figure 7.3. Effect of Inlet Temperature on Retention Time.

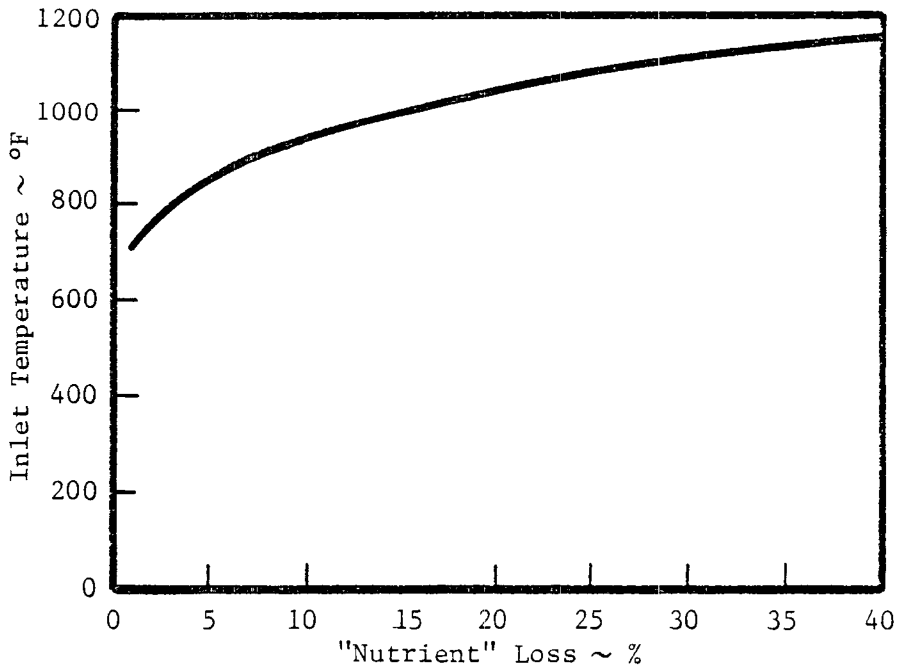

Figure 7.4. Effect of Inlet Temperature on Theoretical Nutrient Loss.

2. As the initial moisture content decreases, the product throughput is increased and the drum operated at a constant value of total water removal rate.

Other operating modes are clearly possible but a consideration of these two will illustrate the general features. Several cases were run simulating the operation of a 30-foot-long triple-pass dryer similar to the Heil SD 105-32. The initial moisture content of the feed material was varied from 55 to 75 percent and the product throughput was fixed at 6800 lb/hr. Under these conditions, the inlet temperature dropped from 1565°F at 75 percent to 504°F at 55 percent moisture content. Similarly the energy required by the dehydrator dropped from 23 million Btu's/hr to 9.8 million Btu's/hr, a saving of nearly 60 percent. Figure 7.6 shows the energy savings relative to the 75 percent moisture level that can be achieved by a reduction in initial moisture content of the feed material.

Similar results in energy savings per pound of dehydrated product are obtained for the second of the operating modes mentioned above. In this case the capacity of the dehydrator in terms of product throughput is greatly increased by lowering the moisture content at the inlet. This increased capacity is approximately a factor of 2.5 in going from 75 percent to 55 percent in initial moisture content. The maximum temperatures experienced by the alfalfa are somewhat higher in this second mode than in the first.

Conclusions

Calculations performed using the numerical model described in this chapter lead to the following conclusions. Under the assumption that major facility and process modifications were undesirable, it was not found to be practical to utilize existing hardware to dehydrate alfalfa to yield a product comparable with that currently produced by the industry using inlet temperatures in the range of 300°F. A large number of variations in process parameters and hardware geometries were examined without finding conditions under which such a dehydration process could be performed efficiently. Low-temperature dehydration in a rotary-drum dryer becomes more feasible if major process innovations such as mechanical dewatering were introduced into the overall processing stream. One variation on this theme involving a rotary steam tube dryer ahead of the low-temperature dehydrator is discussed in some detail in Chapter 6.

The model as it currently exists is an extremely flexible tool for examining the dehydration process in rotary-drum dryers. This model should prove to be of value in examining the dehydration of a number of products such as those discussed in Chapter 10 of this report.

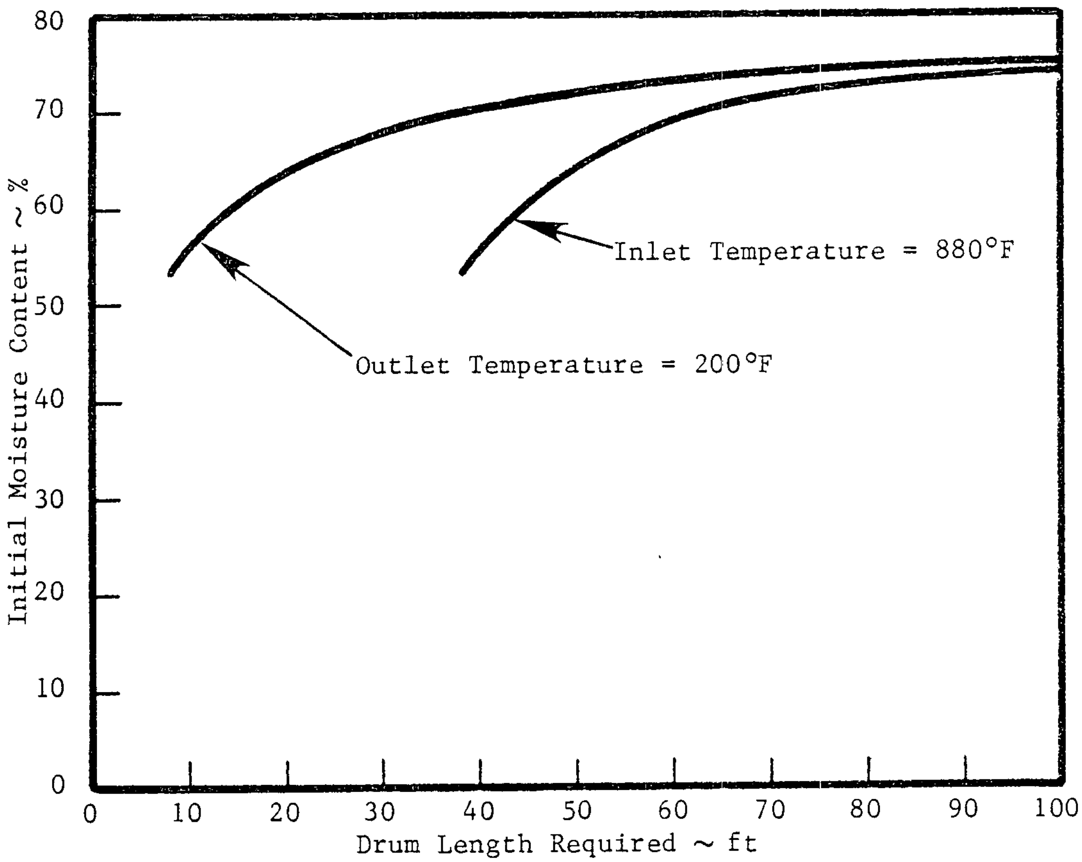

Figure 7.5. Effect of Moisture Content on Drum Length.

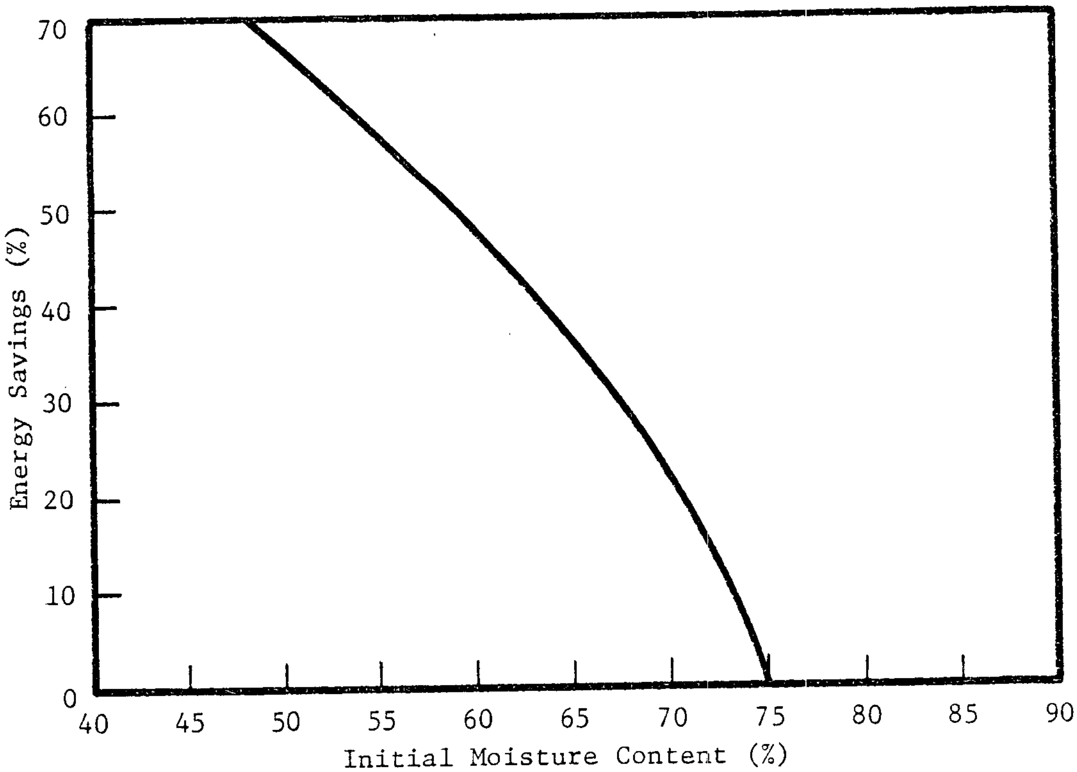

Figure 7.6. Effect of Moisture Content on Energy Use

CHAPTER 8: DETERMINATION OF THE MARKET ACCEPTABILITY OF ALFALFA DRIED AT LOW TEMPERATURE

The previous chapter demonstrates that conversion of existing drum dryers to low-temperature operations is impractical. However, the use of conveyor-type dryers to achieve high throughput with low temperatures and long dwell-time simultaneously is potentially possible. This represents our Case 6 and is similar to the system employed at Broadlands Lucerne Co. in New Zealand. Therefore, if long dwell-time, low-temperature operation is at all feasible, the question remains: how will the nutrient value of the alfalfa be affected by this type of drying cycle? This issue is addressed in this chapter.

Alfalfa is a desired ingredient in animal-feed rations for its green color (it masks other ingredients), its yellow pigmentation (for poultry), its high protein content, and its vitamins and minerals. Certain unidentified growth factors also have been associated with alfalfa. Dehydrated alfalfa is produced in various grades, usually defined as percent of protein. Higher grades (17 to 22 percent) are required for those animals that do not ruminate (form a cud), because these nonruminating animals, such as poultry and swine, cannot digest the large portions of cellulose fiber found in lower grades of dehy.

The market for dehy in the western geothermal areas of the United States is for the higher grades of dehy, since most dehy goes into poultry feed. This is true for both local and export markets. Those dehy components most desired in poultry are xanthophyll (for yellow pigmentation), protein (essential amino acids such as tryptophan and lysine), vitamin A (from carotene), and other vitamins and minerals. Xanthophyll is the most valuable ingredient that dehy contributes to poultry feed from a market standpoint. If xanthophyll were not required in the ration, dehy would have little competitive advantage over competing feed ingredients and would enter the ration at a much lower price.[1] Also, and most important for our purposes, xanthophyll value in dehy can serve as a good overall quality index because conditions that allow high-xanthophyll meal will produce a meal high in carotene (provitamin A), alpha-tocopherol (vitamin E), and other nutrients.[2] Although we also examine protein, xanthophyll retention will be the focus of this evaluation.

Protein

Alfalfa is well known as a first-rate protein source (i.e., source of essential amino acids), and relative amounts of the essential amino acids are particularly important in poultry and swine nutrition.[3] Since protein or amino-acid degradation is associated with high front-end or inlet temperatures,[4] amino-acid losses may not be as great with a low-temperature dryer. It is well known that heating causes loss of amino acids, especially lysine, in products other than alfalfa.[5] In another paper by A. L. Livingston and others, amino acid loss, especially lysine, was shown to be associated with increasing outlet temperatures and lower meal moisture levels.[6] In fact, significant advantages may result with low-temperature drying: conclusions in a test of 111 samples of commercial dehy from various regions of the United States by H. H. Goering have shown that the frequency of accidental overheating is causing the nitrogen present to be undigestible or nutritionally unavailable in many commercial dehydrated-alfalfa samples.[7]

Xanthophyll

Under conventional dehydration conditions, xanthophyll losses occur as a function of reduced moisture apparently independently of high temperatures.[8] The xanthophyll isomer most effective in pigmentation (lutein) is also the most stable and may even increase during dehydration.[9] Much of the research directed at monitoring nutrient losses is designed to show consequences of nutrient loss from overdrying or overheating alfalfa under conventional conditions. Because so little is known about the underlying causes of loss, we must be cautious in carrying over these results to the very different situation with a low-temperature dryer.

Fortunately, the Broadlands Lucerne Company, a geothermal alfalfa drying business in New Zealand, is operating under drying conditions similar to those that a low-temperature geothermal dryer would require and is supplying almost exclusively to poultry. The designers of the Broadlands dryer--Fisher and Paykel Engineering Ltd.--have supplied us with an analysis of the dehy product from this plant along with a detailed description of the drying operations. This analysis shows a xanthophyll quality comparable with that currently on the market in the West. Table 8.1 shows that the Broadlands meal has a protein content close to 20 percent, while the xanthophyll concentration is in the range of that normally found in conventionally dried 17-percent dehy. The presently marketed grade in the western United States is 17-percent dehy. We feel these nutrient-quality consequences resulting from a low temperature and long retention time in a commercial dryer are strong support for the market acceptability of meal dried with this unconventional regime.

Even though most conventional nutrient studies are not very useful, experiments performed to demonstrate losses experienced as a result of prewilting and losses obtained by sun curing alfalfa will give some indication of the outside limits of losses and the kinds of losses to expect under longer-than-normal retention times in a low-temperature dryer. When alfalfa is prewilted, a practice undertaken to reduce energy costs, the dehydration temperature must be lowered to prevent overheating or scorching. Sun curing is accomplished by leaving the cut alfalfa in the field for two or three days. In both situations, the alfalfa is dried for longer times and at lower temperatures.

Sun curing can result in substantial losses of xanthophyll. Livingston shows losses of around 60 percent compared to the averaged xanthophyll values of freeze-dried samples.[10] Sun-cured samples can vary greatly in quality, however, since weather conditions can change the rate of drying and the potential for losing overdried leaves during harvesting is always present.[11]

Table 8.1

A COMPARISON OF CONVENTIONAL DEHY MEAL
TO LOW-TEMPERATURE-DRIED MEAL

Quality Parameter	Conventionally Processed (1600-1800°F Inlet) (2-4 min. retention time) 17% Dehy	Broadlands Low-Temperature (200-290°F Inlet) (30-45 min. retention time) Alfalfa Meal	Conventionally Processed (1600-1800°F Inlet) (2-4 min. retention time) 20% Dehy
Protein	17.0%	20.99%	20.0%
Fat	3.0%	3.62%	3.6%
Food Fiber	24.1%	19.94%	21.1%
Vitamin A	220 MIU/kg	288 MIU/kg	309 MIU/kg
Xanthophyll	240 ppm	254 ppm	310 ppm

SOURCE: Private Communication with Fisher and Paykel Engineering Ltd., Auckland, New Zealand, and R. D. Taylor et al., Alfalfa Meal in Poultry Feeds--An Economic Evaluation Using Parametric Linear Programming, Economic Research Service, Agricultural Report No. 130, USDA, 1968, p. 17.

The situation is not the same when prewilting is done. Although significant losses can occur when prewilting the cut alfalfa prior to dehydration, high-quality dehy has been produced.[12]

Prewilting is accomplished by leaving the freshly cut alfalfa in the field to air dry for two to ten hours before putting it into a dehydrator. Although Livingston shows that significant losses of carotenoids (xanthophyll and carotene) can occur, his data show that good retention of both carotenoids can be obtained for alfalfa left in the field for four hours prior to dehydration (see Table 8.2).[13] The xanthophyll concentrations for direct-cut dehy and four-hour wilted dehy are close to what one would expect from 19-percent-protein meal.[14] It is possible, therefore, to demonstrate only a minor quality distinction between four-hour-wilted-and-dehydrated and straight dehy meal.

Carotene shows somewhat greater damage from wilting than xanthophyll, possibly because carotene is more susceptible to enzyme breakdown. This problem is minimized when freshly cut alfalfa is dried rapidly in a dehydrator--a procedure which quickly destroys the enzyme activity.

Prewilting may be a necessary step with low-temperature drying if retention times are to be kept short. Robert L. Ogden at the University of Nebraska has suggested that a combination of prewilting and low-temperature drying for longer retention times might still produce a high-quality dehy, since the prewilting would lower the temperature necessary to denature or blanch the oxidizing enzymes.[15] The possibility of prewilting followed by low-temperature drying is being addressed in this assessment.

Good results with prewilting may point to similar consequences with geothermal drying. Prewilting causes no apparent reduction in the essential amino-acid composition, and prewilting for short periods "can result in an increase in the level of nonprotein nitrogen which may be advantageous for certain feeds purposes."[16] This observation is very interesting for us, since "nonprotein nitrogen may be more available than protein nitrogen for certain poultry such as broilers or turkey poults."[17] Another benefit of prewilting may be increased digestibility of the cellulose fraction.[18]

To summarize, experiments with sun-cured and wilted alfalfa show it is very likely that a high-quality dehy can be produced with low-temperature drying, although some minor carotenoid losses might occur that would not be realized with conventional drying. Quality should be at least as good as prewilted material, since drying at geothermal temperatures of 200 to 300°F would denature the nutrient-degrading enzymes in a much shorter time than wilting at air temperatures before chopping. In addition, certain nutritional advantages may result from drying at lower temperatures:

- Increases in nonprotein nitrogen may be possible.
- Cellulose digestibility may be improved.
- Protein stability and digestibility may be enhanced. Even an increase in lysine, an essential amino acid for poultry, has been reported.[19]

These observations, together with the experience in New Zealand, leave us satisfied that the alfalfa meal produced by a low-temperature geothermal dryer would be marketable and of good commercial grade.

Table 8.2

EFFECTS OF WILTING ON XANTHOPHYLL AND CAROTENE RETENTION*

Field Treatment	% Moisture		Drying Temp.		Carotene	Protein	Xanthophyll		
	Green Chop	Dehy Meal	Inlet (°F)	Outlet (°F)	% Retention (wilt & dehy)	%	% Retention (wilt & dehy)	ppm Green Chop	ppm Wilt & Dehy
Direct cut	76.9	6.0	1100	250	87	19.4	88	293	258
Windrow									
4 hours	64.2	4.6	850	212	74	19.2	90	265	259
6 hours	57.7	5.8	**	223	74		76	234	217
10 hours	50.3	6.1	550	195	64		65	231	187
23 hours	41.3	5.4	**	199	47		52	193	149

*Weather conditions: temperature, 79-91°F; humidity, 50-77%; and wind, 17-27 knots.

**Not reported.

SOURCE: A. L. Livingston et al., "Nutrient Changes During Alfalfa Wilting and Dehydration," Journal of Agriculture and Food Chemistry, preprint (February 1, 1977); "Advantages and Cautions in Wilting Alfalfa Prior to Dehydration," Feedstuffs (February 7, 1977), p. 30.

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3. A. L. Livingston et al., "Amino Acid Stability During Alfalfa Dehydration," Agricultural and Food Chemistry, Vol. 19, No. 5 (September-October 1971), p. 947.

4. Personal communication from G. O. Kohler, Chief of Operations, Western Regional Research Laboratory, USDA, Albany, CA.

5. A. L. Livingston, D. D. Kusmosky and G. O. Kohler, "Amino Acid Contents of Dehy Alfalfa Meals," Feedstuffs, Vol. 44, No. 5, January 31, 1972, p. A4.

6. A. L. Livingston et al., "Xanthophyll, Carotene, and alpha-Tocopherol Stability in Alfalfa as Affected by Pilot- and Industrial-Scale Dehydration," p. 5.

7. H. K. Goering, "A Laboratory Assessment on the Frequency of Overheating in Commercial Dehydrated Alfalfa Samples," Journal of Animal Science, Vol. 43, No. 4 (1976), p. 869.

8. A. L. Livingston et al., "Xanthophyll, Carotene, and alpha-Tocopherol Stability in Alfalfa as Affected by Pilot- and Industrial-Scale Dehydration," p. 5.

9. A. L. Livingston, "Xanthophyll and Carotene Loss During Pilot- and Industrial-Scale Alfalfa Processing," Agricultural and Food Chemistry, Vol. 16, No. 1 (January-February 1968), p. 84.

10. A. L. Livingston et al., "Estimation of Nonepoxide Xanthophyll in Sun-Cured and Freeze-Dried Alfalfa, Clovers, and Grasses," Journal of the AOAC, Vol. 52, No. 3 (1969).

11. In this same report one of the sun-cured samples lost 83 percent, while another lost 37 percent of the xanthophyll measured in the averaged freeze-dried samples.

12. A. L. Livingston et al., "Nutrient Changes During Alfalfa Wilting and Dehydration," Journal of Agriculture and Food Chemistry, preprint (February 1, 1977).

REFERENCES (Cont.)

13. Ibid.

14. R. D. Taylor et al., Alfalfa Meal in Poultry Feeds--An Economic Evaluation Using Parametric Linear Programming, p. 9.

15. Personal communication, January 25, 1977.

16. A. L. Livingston et al., "Nutrient Changes During Alfalfa Wilting and Dehydration," p. 9.

17. Ibid., p. 8.

18. A. L. Livingston et al., "Advantages and Cautions in Wilting Alfalfa Prior to Dehydration," Feedstuffs (February 7, 1977), p. 30.

19. In the most recent prewilting study, Livingston reports a significant and unexplained increase in lysine after 10 hours of wilting. A. L. Livingston et al., "Nutrient Changes During Alfalfa Wilting and Dehydration," p. 8.

CHAPTER 9: THE HEBER KGRA, A CASE STUDY

Introduction

To test the generalized estimates of the earlier analyses, the study team applied the economic and institutional findings to a particular and real case: the Heber KGRA. In this application site-specific parameters were substituted for generalizations, and the economics of production as seen through the eyes of a dehydrator was substituted for more theoretical computations. Because the earlier findings were generally pessimistic, we chose the best site we could find, from the standpoint of the resource as well as the alfalfa operation, for this more detailed probe. In this portion of the study we worked with the United Alfalfa Mills dehydrating company; their cooperation and assistance were excellent and much appreciated.

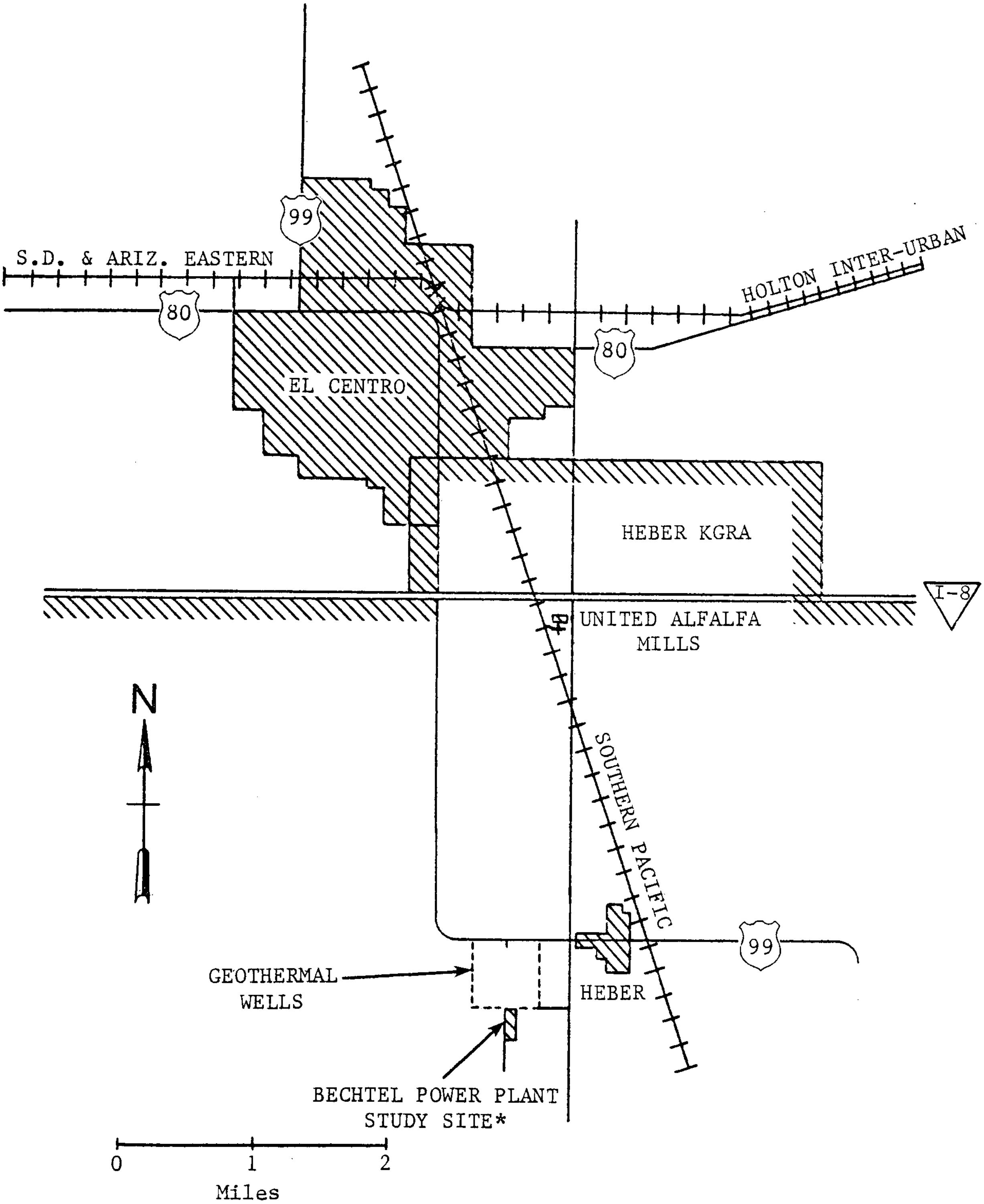
The El Centro/Heber KGRA Site

United Alfalfa Mills is located on a rail siding of the Southern Pacific Railroad, a quarter-mile south of Interstate 8 and about 2.5 miles southeast of the center of El Centro (see Figure 9.1). Across the road to the north of the dehy plant is the Valley Nitrogen Plant, subject of another geothermal direct-utilization feasibility study. Three miles to the south is the center of the Heber anomaly with its concentration of geothermal wells.

The dryers at this site consist of two 18,000 pounds/hour (evaporative capacity) drums and two 22,000 pounds/hour drums. The four drums together can produce about 12 dry tons/hour of 12-percent moisture, 17-percent protein dehy--this is quite a large plant. All dehy is exported to Japan (a Japanese company is part owner of the plant) for use in poultry feeds. Dehy production accounts for 50 percent of United's 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 250-mile radius, is supplied by truck.

Green-chop alfalfa is delivered in plant-owned trucks from independent growers mostly within 10 miles of the plant. Perhaps 20 percent of the alfalfa comes from farms 10 to 20 miles away. The climate and irrigation permit 11 cuttings of alfalfa annually for a year-round plant operating season.

The Heber KGRA occupies an area of about 13.5 sq. miles. The KGRA lies at the southern end of the Imperial Valley. For the most part the land in the KGRA is used for agricultural purposes. Approximately 17 percent of the land in this county is used for growing crops. The most important crops are alfalfa, cotton, and sugar beets, and the total value of agriculture was $520 million in 1976.



*location approximated from J. W. Hankin et al., "Conceptual Design and Cost Estimate for a 10-MWe (Net) Generating Unit and Experimental Facility Using Geothermal Brine Resources," Proceedings: Second U.N. Symposium on the Development and Use of Geothermal Resources, San Francisco, Calif., May 20-29, 1975 (Washington, D.C.: U.S. Government Printing Office, 1976), pp. 1985-1996.

Figure 9.1 El Centro Dehy Plant and Heber KGRA

The Electric Power Research Institute (EPRI) has funded a study of the feasibility of a 50 MWe binary-cycle electric generation demonstration plant at Heber. In addition, under ERDA funding the potential use of the geothermal resource by the Valley Nitrogen Plant is being studied. The general dimensions of the Heber KGRA are illustrated in Figure 9.2.

The details of the Heber KGRA are considered proprietary by the leaseholders (Chevron, San Diego Gas and Electric Company, and Magma Energy, Inc.). Published information indicates that subsurface temperatures are about 375°F and that the total useful potential of the KGRA is 973 megawatts (electrical) or 41.5 billion Btu's/hr.[1]

Water-quality data for the Heber site appears in Tables 9.1 and 9.2. On the basis of the water-quality data, the following were identified as potential problems to be resolved in any design for this site:

- Scaling--because of the high solids content, deposition of solids on the heat-exchanger surface is expected.

- Corrosion--the type of corrosion depends on the materials used. For stainless steels the prevalent corrosion mechanism is expected to be pitting corrosion resulting from chloride attack. Carbon steels are expected to undergo oxygen-type corrosion attack. Most titanium alloys would not be expected to undergo significant corrosion in the presence of Heber brines, which are less concentrated than seawater.

- Chemical attack--the biggest area of concern related to materials selection is the possibility of chemical reactions within the brine itself resulting in a lower brine pH. This could occur by oxidation of dissolved H_2S and other sulfides in the presence of either dissolved oxygen or air.

Scaling. Tests performed by Chevron at their Heber test site indicate that scaling is not as prevalent as at Niland and other locations in the Imperial Valley. Two types of heat exchangers are being tested--carbon-steel and titanium. There was considerable fouling in the carbon-steel tubes, while the titanium tubes, as would be expected, showed only slight scoring and corrosion.[2]

Soft scale may result, under certain conditions, from a decrease in the solubility of dissolved solids as the energy is transferred from the brine to dryer air or other working fluid and the brine temperature decreases. In tests at Niland and Salton Sea KGRAs, soft-scale formation was observed to occur at rates up to 1 in/week in some cases.[2] In order to prevent soft-scale build-up, and to minimize the accumulation of hard salts, it was decided to maintain a brine velocity through all heat-transfer equipment of at least 4 ft/sec in our preliminary designs. This decision was reached after consultation with Chevron's consulting engineering firm,[3] and with other design specialists.[4,5] The penalty for the high velocity is a high pressure-drop (24 psig or more for the specified capacity) and some loss of flexibility in configuration of heat-transfer equipment.

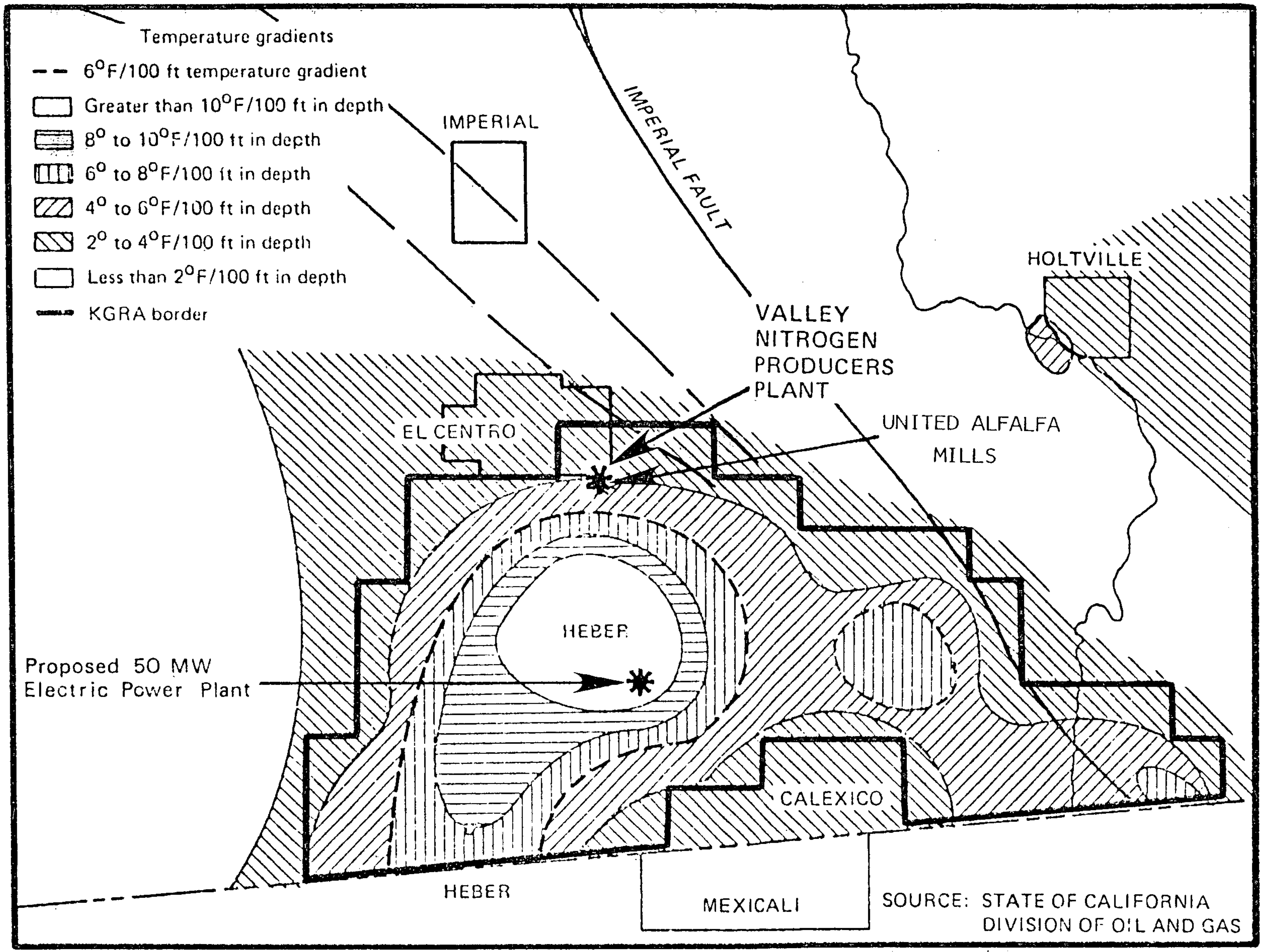


Figure 9.2. Heber KGRA and the United Alfalfa Mills

Table 9.1

CHEMICAL QUALITY OF WATER, HEBER GEOTHERMAL RESERVOIR
IMPERIAL VALLEY, CALIFORNIA

Parameter*	Nowlin No. 1	Holtz No. 1	Holtz No. 2	C.B. Jackson No. 1	J.D. Jackson No. 1
TDS	14,100	13,168	16,330	15,430	15,275
SiO_2	120	268	187	267	268
Li	6.6	4	4.1	2.8	3.4
Na	3,600	5,500	4,720	4,688	4,563
K	360	220	231	181	197
Ca	880	1,062	1,062	891	781
Mg	2.4	5.6	23	4.7	3.8
Cl	9,000	7,420	8,242	8,320	8,076
SO_4	100	100	148	152	150
CO_3	4	NA	NA	NA	NA
HCO_3	20	NA	NA	NA	NA
F	1.6	1.7	1.5	0.9	0.6
B	4.8	4.1	8	4.8	5.2
Fe	0.9	15	5	20	10
Mn	NA	0.9	0.9	1.3	1.9
Pb.	0.1	1.6	0.6	0.6	0.9
Zn	0.68	0.3	0.1	0.4	0.5
Cu	0.2	0.5	0.4	0.4	0.4
Ba	NA	6	3	3	3
Sr	NA	37	42	32	36
Al	0.04	15	12	0.5	18
Ag	NA	NA	NA	NA	NA
Li	4	NA	NA	NA	NA
pH	7.1	NA	7.4	5.8	6.5

*Except pH, all parameters are in parts per million.

SOURCE: "Engineering and Economic Feasibility of Utilizing Geothermal Heat from the Heber Reservoir for Industrial Processing Purposes at Valley Nitrogen Producers, Inc., El Centro Agricultural Chemical Plant," First Quarterly Report prepared by WESTEC Services, Inc., for Energy Research and Development Administration and Valley Nitrogen Producers, Inc., under ERDA Contract E(04-3)-1323, San Diego, California, January 28, 1977.

Table 9.2

CHARACTERISTICS OF THE HEBER GEOTHERMAL RESERVOIR

Total Dissolved Solids (TDS)	14000 ppm
Brine chemistry for thermodynamic calculations	14000 ppm solution of NaCl
pH	6.2
CO_2 by weight of flashed steam	$\leq$0.3%
Methane and hydrogen sulfide by weight of flashed steam	trace
Pressure/Temperature (2 phase brine at well head)	85-100 psi 300-340°F
Brine return temperature at reinjection well	$\geq$160°F

SOURCE: "Engineering and Economic Feasibility of Utilizing Geothermal Heat from the Heber Reservoir for Industrial Processing Purposes at Valley Nitrogen Producers, Inc., El Centro Agricultural Chemical Plant," First Quarterly Report prepared by WESTEC Services, Inc., for Energy Research and Development Administration and Valley Nitrogen Producers, Inc., under ERDA Contract E(04-3)-1323, San Diego, California, January 28, 1977.

Hard scaling consists of the precipitation of a hard layer of predominately amorphous silica on the surfaces in contact with geothermal brine. Silica scale also contains large quantities of heavy-metal sulfides, and metals such as iron, copper, silver and lead, all of which contribute to the scaling problem.[1]

As the geothermal water cools, it becomes supersaturated with amorphous silica which deposits at a rate determined by the presence of minerals, such as calcium oxide, which catalyze the precipitation. It is rather difficult to predict the rate of buildup of hard scale from geothermal brines, although deposition rates in the Salton Sea KGRA are observed to be on the order of 1/8 in/year. Since the Heber reservoirs all contain significantly less solids than found at Salton Sea, the latter rate of scale formation may be taken as an upper limit for design purposes. In order to allow for the possibility of hard-scale formation on heat-transfer surfaces, the following provisions were made:

- Brine flow will be on the tube side of heat exchanger; and
- The design will include provision for taking parts of the heat-exchanger system out of service for periodic cleaning without interrupting brine flow. The arrangement tentatively selected has two independent parallel circuits, each with three sets of coils in series.

Corrosion. Chevron Oil Field Research personnel have been involved in the material and corrosion problems at the Heber KGRA. Corrosion-rate studies have involved both probes and heat-exchanger tubes. The test program was of approximately one year's duration.[2] Corrosion rates on blade, coupon and rod probes range from 10 to 80 mils/year (0.01 to 0.08 in.), indicating very severe corrosion; however, tube tests using titanium tubes indicated satisfactory performance.

Bureau of Mines tests at the San Diego Gas and Electric Company/ERDA geothermal loop experimental facility at Niland were performed using a natural brine from the U.S. Bureau of Reclamation well site near Holtville. This brine, containing 3 percent dissolved solids, is believed to be similar to that found at Heber KGRA. Titanium and titanium alloys (Ti-1.7 W, Ti-2 Ni, and Ti-10 V) all exhibited either very slight or nondetectable corrosion rates at 220°F and 1 atmosphere, using either aerated or deaerated brines. Under these conditions, carbon steel exhibited severe corrosion, while Types 302, 316L, Carpenter 20, and E-Brite 26-1 all exhibited slight to nondetectable rates of general corrosion and pitting, or crevice corrosion. These findings are basically in agreement with the qualitative results on Heber brines published by Chevron.[2]

In addition to published data, we have been able to acquire verbal descriptions of additional tests performed by Chevron, which indicate that carbon steel tubes show acceptable lifetimes under Heber brine conditions provided that (a) tubes are cleaned prior to being placed in service, and (b) air is prevented from entering the system.[3]

In summary, either titanium, titanium alloys, or stainless steel may be expected to show acceptable service lifetimes under Heber brine conditions, if proper care is taken in design not to exceed material limitations. Titanium and titanium alloys are frequently used in applications, such as in desalination and cooling, where brines are used in contact with heat-transfer surfaces. In such applications, service lifetimes have been excellent (for example, 90-percent probability of 30-year lifetime in power-plant cooling application[6]) but the cost of titantium heat exchangers ($\$40/ft^2$ FOB) is almost prohibitive for geothermal applications where large heat-transfer surfaces are required. For this reason, and because there is some reasonable doubt about the service life of carbon steel tubes in contact with Heber brines, we have elected to base design costs on the use of type 304 stainless steel tubes.

Chemical attack. Chemical attack of heat-exchanger tubes by acids (H^+) can result from oxidation of sulfides (mostly H_2S) present in some geothermal brines. There are to date no known measurements of the incondensable gas fraction from the KGRAs in the Imperial Valley. The fraction of geothermal fluid at Heber KGRA comprised of incondensable gas is about 0.3% (by weight), which is comparable to the Geysers field.[7] The only indication of the H_2S concentration in the Heber brine is based on measurement of emissions from the San Diego Gas and Electric/ERDA geothermal experimental station at Niland. Concentrations of H_2S have been found to vary from 1500 to 4900 ppm by volume at the Niland facility. This level is significantly less than the 5.7 percent found at the Geysers, and would not reduce the pH of the brine solution to levels below those found in Table 9.1, even if the brine were thoroughly aerated. Therefore, it does not appear that additional precautions need to be taken to prevent chemical attack other than those previously discussed in connection with materials selection.

Estimate of Heat Costs

Two sources were used to obtain estimates of the cost of delivered heat to the United Alfalfa Mills. We requested estimates from Chevron Resources Company and the Battelle Pacific Northwest Laboratories GEOCITY model was used to perform a larger range of economic analyses.

The Chevron Resources Company provided an estimate of the investment (wells, facilities, and pipelines) and operating cost schedule that would be required to deliver geothermal heat in accordance with conditions specified by the study team. These conditions were

- 925,740 pounds per hour of liquid-phase brine (for present dehy output)
- 300°F delivered temperature
- 160°F return temperature

The Chevron estimate was based on a net cash flow analysis for various scenarios. Table 9.3 presents this data.

Table 9.3

CHEVRON ESTIMATES OF THE COST OF DELIVERED HEAT

38% Annual Dryer Capacity			57% Annual Dryer Capacity*		
Price $/M BTU	Life	Pipeline**	Price $/M BTU	Life	Pipeline**
4.90	10 years	with	3.25	10 years	with
2.50	10 years	without	1.80	10 years	without
4.35	20 years	with	3.00	20 years	with
2.15	20 years	without	1.50	20 years	without

*432 and 648 billion Btu's/year required for present (40,000 tons/year) and 150% of present output, respectively.

**With and without pipeline investment.

For the conditions that were assumed, it appears that the price of geothermal heat in this location for a 12-ton per hour dehy output ranges from about $1.50 per million Btu's to $5.00 per million Btu's. The analysis indicates that the price is quite sensitive to capacity factor and assumed project life. The pipeline represents a major investment if the dehy plant remains at its present site. The pipeline length would be about three-and-one-half miles from the supply well and about two-and-one-half miles to the reinjection well.

The Battelle analysis using the GEOCITY model involved consideration of 12 separate cases. These cases are illustrated in Figure 9.3. Cases 1, 4, 7 and 10 depict a geothermal-fluid transmission system shared by Valley Nitrogen Plant (VNP) and United Alfalfa Mills (UAM) at their present sites (3.5 miles from the Heber reservoir). Cases 2, 5, 8 and 11 represent a pipeline that serves only UAM at its present site. Cases 3, 6, 9 and 12 represent a pipeline that serves only the alfalfa mill, but the mill is moved to within one mile of the Heber reservoir. One mile is estimated to be the least distance that would still permit the mill to locate on a rail siding for export shipping.

The VNP demand was assumed to require a flow rate of about 82,792 lb/min and the annual load factor is 0.75. The average annual load factor for Cases 1, 4, 7 and 10 was calculated with the following equation:

$$LF_{avg} = \frac{(0.75)\ (82{,}792) + (LF_{UAM})\ (F_{UAM})}{82{,}792 + F_{UAM}}$$

Where

LF_{avg} = Average annual load factor

LF_{UAM} = Annual load factor for UAM

F_{UAM} = Flow rate of the 360°F Heber fluid required by UAM, lb/min.

The assumptions and an example of the computer printout are included in Appendix B.

	Description	Dryer Requirements	Annual Load Factor
Case 1	Pipeline shared by VNP and alfalfa mill at present site. Distance from VNP to alfalfa mill assumed zero.	Brine flow: 15, 429 lb/min Inlet Temperature: 300°F Return Temperature: 160°F Inlet Pressure: 100 psia Return Pressure: 20 psia	.38
Case 2	Alfalfa Mill at present site: pipeline serves <u>only</u> alfalfa mill.	As for Case 1	.38
Case 3	Alfalfa mill moves to site for which pipeline length is 1 mile; serves <u>only</u> alfalfa mill.	As for Case 1	.38
Case 4	As for Case 1	As for Case 1	.57
Case 5	As for Case 2	As for Case 1	.57
Case 6	As for Case 3	As for Case 1	.57
Case 7	As for Case 1	Brine flow: 7,714 lb/min Other parameters as above	.38
Case 8	As for Case 2	As for Case 7	.38
Case 9	As for Case 3	As for Case 7	.38
Case 10	As for Case 1	As for Case 7	.57
Case 11	As for Case 2	As for Case 7	.57
Case 12	As for Case 3	As for Case 7	.57

Figure 9.3 GEOCITY Case Descriptions

Table 9.4 shows the wellhead cost of energy, the delivered cost of energy, and the transmission system capital cost for each case. The energy costs include 10¢/MBtu for downhole pumps to suppress flashing in the wells. The transmission system capital cost includes the costs of the transmission pipe, insulation, booster pumps, and return pipe to the injection wells. All GEOCITY costs are in July 1976 dollars.

Based on the results of the analyses shown in Table 9.4, the pipeline shared by VNP and UAM yields lower energy costs in all cases except Case 6, in which two unlikely assumptions are made--that UAM moves from its present site and that it produces 150 percent of present dehy output.

Comparison of the Chevron and GEOCITY Estimates

The GEOCITY model and the Chevron estimate were, of course, attempts to determine the economics of supplying geothermal heat to United Alfalfa Mills. As is clear from the preceding discussion, these estimates differ. Table 9.5 presents a comparison of the estimates. The difference is primarily in the figures assigned to the wellhead costs for the geothermal energy, the Chevron estimates being higher ($2.50 versus $1.14 with the 38 percent annual dryer load factor, GEOCITY Case 2). With respect to transmission, cost estimates are comparable ($2.40 versus $1.99). At this point the study team is not certain about the reason for the discrepancy. It may well be that investment is higher than assumed by the GEOCITY model or that required return on investment is higher than anticipated by Battelle.

The United Alfalfa Mills Scenario

The GEOCITY costs indicate that a pipeline shared between the Valley Nitrogen Plant and United Alfalfa Mills is probably most cost-effective. The Chevron price estimates have been used for economic analysis since, after all, Chevron is selling the heat. Since the Chevron estimates do not include a shared pipeline, we have used the ratio of wellhead price (per million Btu's) when the pipeline is shared to wellhead price when the pipeline serves only UAM from the GEOCITY model and applied this ratio to the Chevron wellhead price. A similar process was used to estimate the Chevron cost for pipeline transmission. The two components, wellhead price and transmission cost, were then added to produce final estimates of the delivered price. (The same technique was used to estimate the Chevron price for one-mile pipeline delivery of heat. It should be noted that this technique, and the estimates it produced, have not been validated by Chevron.)

Table 9.4

CAPITAL AND ENERGY COSTS FOR SINGLE-PHASE GEOTHERMAL FLUID FLOW FROM THE HEBER RESERVOIR TO THE ALFALFA PLANT

Case No.	Distance From Reservoir To Plant, Miles	Distance From Plant To Injection Wells, Miles	Geothermal Fluid Flow Rate, lb/min	Average Annual Load Factor	Wellhead Cost of Energy, $/MBTU *	Delivered Cost of Energy, $/MBTU *	Transmission System Capital Cost, $M**
1	3.5	2.5	91,744	0.71	0.84	1.45	3.43
2	3.5	2.5	10,703	0.38	1.14	3.13	1.25
3	1.0	1.0	10,703	0.38	1.14	1.97	0.38
4	3.5	2.5	91,744	0.73	0.82	1.41	3.43
5	3.5	2.5	10,703	0.57	0.78	2.16	1.25
6	1.0	1.0	10,703	0.57	0.78	1.39	0.38
7	3.5	2.5	87,268	0.73	0.82	1.43	3.35
8	3.5	2.5	5,351	0.38	1.28	4.23	0.92
9	1.0	1.0	5,351	0.38	1.28	2.52	0.28
10	3.5	2.5	87,268	0.74	0.80	1.41	3.35
11	3.5	2.5	5,351	0.57	0.89	2.90	0.92
12	1.0	1.0	5,351	0.57	0.89	1.75	0.28

* Includes 10¢/MBTU for downhole pumps; cost of field identification and exploration has been omitted because the Heber reservoir has been developed already.

**Includes transmission pipe, insulation, booster pumps, and return pipe to injection wells.

Table 9.5

COMPARISON OF CHEVRON AND GEOCITY ENERGY PRICE ESTIMATES
Cost per million Btu's

Description	38% Annual Load Factor		57% Annual Load Factor	
	Chevron	GEOCITY	Chevron	GEOCITY
Pipeline shared by VNP and UAM	$2.58*	$1.45 (Case 1)	$2.51*	$1.41 (Case 4)
°Wellhead cost	1.84*	.84	1.89*	.82
°Added cost for delivery to UAM	.74*	.61	.62*	.59
Pipeline serves UAM only, present site	$4.90	$3.13 (Case 2)	$3.25	$2.16 (Case 5)
°Wellhead cost	2.50	1.14	1.80	.78
°Added cost for delivery to UAM	2.40	1.99	1.45	1.38
One-mile pipeline to UAM only, new site	$3.50*	$1.97 (Case 3)	$2.44*	$1.39 (Case 6)
°Wellhead cost	2.50*	1.14	1.80*	.78
°Added cost for delivery to UAM	1.00*	.83	.64*	.61

Assumptions Peak brine demand 15,429 pounds/minute
Inlet Temperature 300°F
Return Temperature 160°F

Pipeline Amortized in 10 years

*Indicates estimated by The Futures Group, not Chevron (see text).

For the shared pipeline scenario, then, the price of delivered heat can be estimated as follows:

- Annual load factor, transmission system	0.71
- Wellhead price per million Btu's	\$1.84
- Transmission cost per million Btu's	\$0.74
- Total price per million Btu's	\$2.58

Thus, a scenario for the use of geothermal energy by United Alfalfa Mills involves the following:

- A joint venture with the Valley Nitrogen Plant in order to minimize transmission costs using a pipeline from the Heber resource to both plants, with a tee close to the location of the plants.

- A common reinjection line from both plants would also be utilized. Simultaneous and parallel operation by both plants is possible.

- United Alfalfa Mills would replace their current drum dryers with conveyor dryers; in addition the required heat exchangers and ancillary equipment would be added.

Table 9.6 presents an economic analysis of geothermal conveyor-dryer operation according to this scenario. Additional operating and capital recovery costs for the conveyor dryers and heat exchangers, as well as credits for costs that are associated with rotary-drum dehydrator operation. are shown in the same format as the comparison chart in Chapter 6 (Table 6.12). However, many of the assumptions have been changed in order to approximate as closely as possible the conditions at the El Centro site.

Table 9.7 summarizes the salient features of the shared-pipeline, conveyor-dryer scenario. The operator of United Alfalfa Mills felt that the additional \$39 per ton that would be required under the assumed conditions would be prohibitive at the present. He could not pass on the increased cost to the consumers because other products would be substituted for dehy; he felt that he could absorb perhaps an additional \$5-6 per ton in exchange for a secure energy supply.

The price for natural gas would have to rise to about \$5.30 per thousand standard cubic feet in order to offset the additional costs associated with geothermal retrofitting. Increased production of sun-cured alfalfa (see Chapter 3) would be the most likely consequence of a permanent natural gas curtailment or greatly increased price, unless substantial subsidies were made available for geothermal retrofitting (see Chapter 12).

Table 9.6

COSTS OF ALL-GEOTHERMAL CONVEYOR DRYER OPERATION
WITH SHARED PIPELINE FOR UNITED ALFALFA MILLS, EL CENTRO

Fossil Energy Reduction	100%	
Additional Investment (two 6-ton-per-hour modules required)	$3.30 million	
	Total	Additional Cost Per Ton[a]
Operating Costs (annual basis)		
Brine (300°F) at $2.58/million Btu's[b]	$1,113,000	$27.83
Electricity at $0.029/KWh[c]	203,000	5.08
Natural Gas at $1.15/million Btu's[d]	(438,000)	(10.95)
Electricity at $0.029/KWh[e]	(23,200)	(0.58)
Maintenance[f]	100,000	2.50
Supervision (7% of maintenance)[f]	7,000	0.18
Taxes, insurance, G&A (4% investment)[f]	132,000	3.30
Total Additional Operating Costs	$1,093,800	$27.36
Capital Recovery Factor (0.149)[g]	$ 492,000	$12.30
Annual Set Aside for Rotary Drum Replacement[h]	(12,000)	(.30)
Total Additional Annual Cost	$1,573,800	
Total Additional Cost Per Ton Product		$39.36

Table 9.6 (Cont.)

FOOTNOTES

a. 38% annual load factor assumed for 40,000 tons/year dehy production.

b. Cost per million Btu's based on shared pipeline (GEOCITY Case 1); 15,429 lb/min brine flow, 140°F temperature drop through heat exchanger; no charge for unused heat (below 160°F brine return temperature).

c. Electric consumption estimated from Chilton, C. H. (ed) Perry's Chemical Engineer's Handbook (4th ed.) (New York: McGraw-Hill, 1964).

d. Credit for unused natural gas that would be required for rotary dryer at 9.533 million Btu's/ton (baseline condition, Table 6.5, Chapter 6); price per million Btu's is typical mid-1977 for UAM.

e. Credit for unused electricity at 20 KWh/ton, assuming 20% of average 100 KWh/ton (Reference 4, Chapter 3, p. 29) is used for drum dryer rotation, remainder for pelleting, etc.

f. See Chapter 6, Table 6.12.

g. 10-year loan at 8% interest to finance the additional investment.

h. About $2,500/year toward replacement of each of two drum units bought used for $30,000 each, lifetime 12 years; about $3,500/year toward replacement of each of two drum units bought new for $70,000 each, lifetime 20 years.

Table 9.7

SUMMARY OF SHARED-PIPELINE, CONVEYOR DRYER SCENARIO

	Present Conditions	Projected Conditions
Output, tons/hr. of dehy	12	12
Dryer type	4 rotary drums	4 conveyor units
Energy source	Natural gas	100% geothermal
Delivered energy price per ton dehy output	$11-12	$27.83
Capital investment, dryers and heat exchangers	$200,000 (No heat exchanger required)	$3.3 million
Cost of processing,* per ton dehy	$61	$100
Breakeven natural gas price, per ton dehy	-	$50**

*Includes harvesting ($16) and dehydrating ($45), but not price of raw alfalfa input (about $50/dry ton in mid-1977).

**Equivalent to $5.30/million Btu's ($5.30/1000 SCF).

Alternative Configurations

The scenario presented above envisions that United Alfalfa Mills would remain in its current location and share a pipeline with the Valley Nitrogen Plant. There are other possibilities that appear less plausible but that should be mentioned. A separate pipeline might be installed between the Heber facility and the United Alfalfa Mills. This pipeline might be shorter than the one required by the Valley Nitrogen Plant since the inlet temperature used for drying alfalfa could be 300°F (VNP requires 360°F) and therefore the geothermal fluids could be drawn from a well nearer the periphery of the geothermal area. Alternately, if a shared pipeline were not possible, a new site could be found for the plant. This site would be located on a railroad siding and as close as possible to the center of the geothermal resource. Tentatively, a site north of Heber about one mile from the wellhead seems like the best compromise between proximity to the area of most intense drilling activity and availability of rail transport. In both these scenarios the delivered price of geothermal energy would probably still be higher than for the shared pipeline scenario.

A last possibility might be to move the drying facilities to the wellhead itself; the dehy output would have to be shuttled to a rail siding for export in this case. The energy price in this case would be a minimum of about $2.50/million Btu's.

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CHAPTER 10. THE CONCEPT OF MULTICROP DRYING CENTERS

Introduction

The dehydration of alfalfa with geothermal heat has proved to be an unattractive prospect in the United States. The most obvious strategy--the construction of low-temperature, conveyor-type dehydrators at geothermal resources that are located in the midst of alfalfa-growing areas (Chapter 4)--is not likely due to the limited potential for industry expansion. An alternative strategy--retrofitting of existing dehydration sites with geothermal preheat or new dryers--yields only one plant that is both sufficiently near a geothermal resource and confident about its ability to stay in business. Even United Alfalfa Mills, large as it is, probably could not afford the investment in new drying and heat-exchange equipment that would be required in order to utilize geothermal energy.

It is likely that many of the same factors that make geothermal use in the alfalfa dehydration industry difficult would afflict the other drying industries, which are analyzed in this chapter. The supply and price of the raw-crop input to a dehydrating industry is subject to year-to-year variations; economical use of geothermal requires a steady and foreseeable energy demand. A dehydrating industry also must be confident of the future of its product before it is likely to be willing to make a large initial investment in the necessary geothermal heat-exchange equipment. Many crops cannot be dried all year long as alfalfa can be dried in the Imperial Valley: single-crop dryers might well not be able to amortize efficiently the large fixed cost of geothermal heat-exchange equipment for this reason.

Most important, however, is the fact that any geothermal retrofitting strategy for an industry is subject to chance. Putting aside considerations of how efficiently an existing drying plant might use its geothermal investment, it will only make that investment if it is very near to a resource, a few miles at most. However, fossil fuel use by 12 drying industries in each geothermal state and within 50 miles of identified resources is presented in Appendix C and summarized in this chapter to provide an optimistic national estimate of geothermal retrofit potential.

Rather than refine that estimate, this chapter will also present an alternative: multicrop drying centers (MDCs). As long as many drying plants would have to move nearer to geothermal sources in order to conserve a significant proportion of the fossil fuel presently used by U.S. crop-drying industries, why not combine the plants and dry several crops in one? The MDC concept can be extended to areas where no drying plants now exist. The long-run effect may be the same--to conserve fossil fuel as plants using these energy sources are phased out. In addition, the areas near these MDCs might experience increased tax revenues, employment, and other economic benefits. A main purpose of this chapter, then, is to draw up a preliminary list of multicrop drying centers and to rank them in rough order of economic feasibility.

Potential MDC sites had to fulfill several geographical and energy-use efficiency criteria. All sites are located at identified hydrothermal resources that appear to be located on or very near (less than a mile or two from) roads or railroads. All MDC sites are located in or near agricultural areas that grow two or more crops that are commercially dried at present somewhere in the United States. The allowable distance between MDC site and growing area varied with the crop, but in no case was more than 50 miles. A final criterion of an agricultural geography nature was that the growing areas surrounding each MDC site produce amounts of the dryable crops sufficient to warrant commercial drying.

The MDC sites were grouped into high-, medium-, and low-potential groups with these criteria. There are 10 sites in the first group, 15 in the second, and 13 in the third; the sites are located in 9 states. Within each group, the sites are ranked on the basis of a figure of merit, a weighted composite of scores for several parameters. The parameters include a measure of how adequate the U.S.G.S. "best-estimate" of resource temperature is in relation to the air temperature that is needed to dry the selected crops. Other parameters factor in the length of the drying season for the crop combination (the longer, the better capital is amortized, is the assumption); how efficiently geothermal brine might be cascaded from one crop dryer to the next where drying temperature differs and the drying seasons overlap; how many crops might be dried at the center (assumed: the more the better, all other things being equal). Finally, points are given when an MDC would demonstrate important means of reducing the fossil-fuel use for crop drying in the United States.

The MDC concept is not an all-inclusive one--only crop-drying applications of geothermal heat were included to limit the focus to industries that were studied intensively and for which good process data was available. The alternative uses for heat in agriculture that are discussed in Chapter 11 might be incorporated into MDCs in some cases. However, the analysis in the present chapter presents the framework for a possible strategy for geothermal energy use in agribusiness, and for conservation of fossil energy in the agricultural sector. The multicrop drying center strategy is one of those that is discussed in Chapter 12 and that seeks to meet these goals.

Identification of Potential Commodities for Geothermal Drying

Early in the study a literature search was done to assemble data on agricultural commodities that are currently dried or heat processed and to compile a list of the commodities that offer potential for the use of geothermal heat. For each commodity the following information was obtained whenever possible:

- How dried: What process or processes are currently being used to dry the crop?

- Temperature: What temperature is required to dry each crop?

- Quantity dried: How many pounds are currently dried annually and what percentage is this of the total U. S. crop?

- Moisture removed: What is the crop's initial moisture content and to what final moisture content is it dried?

- Energy requirements: How much energy is required per unit of product?

- Timing: During what season does the crop need to be dried?

In the literature search, an attempt was made not only to cover all existing drying and heat processing of crops, but also to contact individuals and associations involved with the drying or heat processing of various commodities. At several points during the survey, information on how much of a particular crop is dried and where it is dried was unobtainable, as this information is often proprietary.

The commodities were grouped into two categories upon completion of the initial literature search. Table 10.1 lists the commodities that seemed to offer moderate to high potential for the commercial application of geothermal heat for drying and dehydrating. These commodities are currently processed in significant amounts in the United States with methods for which the use of geothermal heat between 90°C and 150°C appears to be technically feasible.

Several other crops were examined and rejected for one or more reasons: little or no heat is needed in drying; the dried product is of poor quality and/or has lost its market; the crop is almost exclusively sun-dried; drying is very seldom required. Wheat, oats, soybeans, parsley, dry edible beans, green beans, beets, cabbage, green peas, pumpkins, squash, figs, and dates were all rejected. (Some of these are included in the 10 top crops for each state, and so are analyzed in a later section.) Freeze-dried products--meat and poultry, fish, mushrooms, some tea, and about 30 percent of instant coffee--were not included in order to concentrate on conventional, atmospheric pressure processes.

The commodity information that was compiled for the high- and moderate-potential crops is summarized in Table 10.2. Table 10.3 shows the usual harvest season for these crops.

The following are detailed descriptions of the drying processes for each of the moderate- to high-potential dried crops.

Grain, grasses, and fiber.

1. Corn: Corn is usually removed from the field with a moisture content of 30 percent and must be dried to a 15.5 percent moisture content for safe storage. Shelled corn is purchased on the basis of 56 lb of total weight per bushel at 15.5 percent discounted moisture. Corn above this

Table 10.1

COMMODITIES WITH A POTENTIAL FOR GEOTHERMAL DRYING

GRAINS & GRASSES	VEGETABLES	FRUITS	LIVESTOCK PRODUCTS
corn	potatoes	prunes	milk
alfalfa (hay)	onions	apples	eggs
rice	garlic	apricots	
peanuts	chili peppers	peaches	
seed cotton	carrots	pears	
sorghum	celery	grapes (raisins)	
barley.			

Table 10.2

SUMMARY OF DRYING CHARACTERISTICS

Grains and Fiber crops	Moisture Content Initial	Final	How Much Dried Lb	% of U.S. Crop	How Dried	Temperature (maximum)
Corn	~30	15.5	175 billion (1974)	67	Forced air	140°F (grain)
Alfalfa	60-75	10	2.7 billion (1976-7 dehy)	1.7	Forced air	1800°F
Rice	22-26	12	12.1 billion (1975)	95	Continuous flow	130°F
Peanuts	36-60	7	3.9 billion (1975)	100	Sacks or bin | Continuous dryer	Sacks 120°F | cont. 85°-90°F
Seed cotton	Varies	11	5.4 billion: total 1974 production; dried amount varies year to year (see text)		Vertical baffled dryer	220°F
Sorghum	~10-22	12-13	3.1 billion (1975)	7	Forced air	140°F (grain)
Barley	~10-27	~13	Varies		Bin	110°F
Vegetables						
Potatoes	80	6-8	(1970) 365 million	6-8	Continuous belt	275°F
Onions	88	<4	(1970) 86.5 million	20-25	Continuous belt	160°F
Garlic	62	6.5	(1970) 21.9 million	90	Continuous belt	180°F
Chilis	92	3	(1974) Calif.: 20 million	80-99	2-stage tunnel	150°F
Carrots	88	4	No published statistics available		2-stage tunnel	160°F
Celery	95	4	No published statistics available		2-stage tunnel	180°F

Table 10.2 (Cont.)

Fruits	Moisture Content Initial	Final	How Much Dried Lb	% of U.S. Crop	How Dried	Temperature (maximum)
Prunes	85	16-19	(1974) 209 million (dry basis)	88	Tunnel	165°F
Apples	85	18-20	(1974) 25 million (dry basis)	U.S.-3 Wash 6 Calif.14	Tunnel | kiln	Tunnel: 165°F kiln: 135°F
Apricots		18	(1975) 9.5 million (dry basis) (mostly sun-dried)	U.S.17 Cal.17	Tunnel	150°F
Peaches		25-28	(1974) 3.5 million (dry basis) (mostly sun-dried)	U.S.:1 Cal. 2	Tunnel	155°F
Pears		25-28	1.4 million (mostly sun-dried)	U.S.:1 Cal. 2	Tunnel	155°F
Raisins		10-14	30 million (not sun-dried)	7	Tunnel	about 165°F
Dairy						
Milk Products	87-90	5	3 billion (dry basis, 1974)	20	Spray drying	160°F
Eggs	Whole: 74 Yolk: 51 White: 88	all <2	(1970) 73 million	35-38	Spray drying	138°F

Table 10.3

DRYABLE CROP HARVEST SEASONS

	AZ	CA	CO	ID	MT	NV	NM	OR	UT	WA	WY
Corn	F	9/15-12/1	F	F	F	F	9/10-12/1	F	F	F	F
Alfalfa	3/15-12/1	4/15-10/31	S	S	S	4/10-11/1	5/1-10/20	S	S	S	S
Rice	-	9/20-10/15	-	-	-	-	-	-	-	-	-
Peanuts	-	S	-	-	-	-	10/10-11/10	-	-	-	-
Cotton	9/15-1/15	10/1-11/30	-	-	-	10/15-12/31	9/10-12/15	-	-	-	-
Sorghum	7/5-12/5	9/15-11/20	F	F	F	F	10/10-12/1	F	F	F	F
Barley	5/20-7/5	6/1-8/20	F	F	F	7/10-9/15	6/10-8/1	F	F	F	F
Potatoes	4/15-7/15	All	S,F	F	F	10/10-11/10	5/15-11/15	F	F	F	F
Onions	5/1-7/15	4/1-10/31	7/1-10/31	S	-	S	5/25-10/10	S	S	S	-
Garlic	-	4/1-9/15	-	-	-	-	-	-	-	-	-
Chilis	W	9/15-12/15	W	-	-	-	W	-	-	-	-
Carrots	10/10-7/30	All	ND	-	-	-	-	7/1-12/31	ND	7/15-11/31	-
Celery	-	All	ND	-	-	-	-	-	-	ND	-
Apples	S	7/15-10/30	S	S	S	-	8/15-10/30	S	S	S,F	S
Prunes	S	8/10-9/25	S	S	-	-	ND	S	S	S,F	-
Apricots	ND	6/1-8/10	ND	ND	-	-	ND	ND	S	F	-
Peaches	ND	6/1-9/30	ND	S	-	ND	ND	ND	S	F	ND
Pears	ND	7/10-9/15	ND	S	ND	-	ND	ND	S	F	-
Grapes	ND	7/21-10/20	ND	ND	-	-	ND	ND	S	F	-

S = Summer W = Winter
F = Fall ND = No data available

moisture level incurs a drying charge and corn below this level merits no premium, so either under-drying or over-drying will cost the farmer. Since 1965, between 4 and 5.6 billion bushels of corn have been grown annually in the United States, of which 67 percent is now shelled at harvest time and air dried.

Corn is generally dried by a type of forced-air drying at temperatures no greater than 140°F (grain temperature). After being dried to a 19 percent moisture content, the corn can be stored in a crib that has effective natural ventilation such that the drying can be completed to the required 15.5 percent moisture content. A good rule of thumb for the cost of drying corn by current methods of forced-air drying would be $0.005 to $0.01 per bushel for each 1 percent moisture removed.

Low-temperature drying of shelled corn in the crib can also be employed on corn that has an initial moisture content of 22 to 24 percent, or has been dried at a higher temperature to this point. Although the low-temperature method of drying corn has been used, it is not in as extensive use as the forced-air drying method. Possibly this is because of the many factors involved in the low-temperature drying process, making its use more complex. Factors that must be taken into account are presented below.

a. Average daily relative humidity: A sufficient temperature rise, often less that 10°F, must be used to lower the relative humidity of the air utilized to dry the corn to a 13 to 16 percent moisture content. For example, air with 80 percent relative humidity heated in order to raise the temperature from 40° to 44°F can be used to dry shelled corn down to 15 percent.

b. Timing: Low-temperature drying is a slow process because of the limited capacity of the slightly heated air to absorb moisture. However, the time allotted for drying is limited because drying must be completed in a time frame that is less than the allowable storage time, leaving a safe margin time. The time within which the corn must be dried is also limited by the season of the year. Extending the drying time into early winter is impractical because of the extremely limited capacity of cold air to absorb moisture. Therefore, low-temperature drying needs to be completed before the average daily temperature drops below 30°F.

2. Alfalfa: This crop is discussed elsewhere at length.

3. Rice: Rice has an initial moisture content of 22 to 26 percent and must be dried to a 12 percent moisture content. In the United States, 84 to 104 million hundredweight of rice is produced annually, of which 95 percent is dried. A further analysis of the drying process reveals that 10 to 15 percent of all rice produced is dried on the farm, 20 to 25 percent at the rice mills, and 60 to 70 percent at a commercial dryer.

Rice is generally dried in continuous-flow dryers to about 14.5 percent moisture content. Drying is then completed in storage bins with effective natural ventilation only if the relative humidity of the ambient air is below 75 percent. The dryers are operated at a maximum temperature of 130°F, as the grain temperature should not exceed 110 to 120°F. Three or more drying stages are generally used in rice-drying procedures. The rice is first combined such that the moisture content is 22 to 26 percent. Within 6 hours after combining it is dried for 30 to 45 minutes at 130°F. The second stage in the drying process should begin 6 to 12 hours after completion of the first drying operation. The third drying step (and any additional dryings required to bring the moisture content to 14.5 percent) begins 6 to 12 hours after completion of the previous drying. In this drying operation the rice must be dried for 20 minutes at 130°F. The total heat required to dry 1 barrel of combined rice of average moisture content is 14,000 Btu's.

4. Peanuts: At the time of digging, peanuts have a moisture content anywhere from 36 to 60 percent and must be dried to a 7 percent moisture content. Peanuts are normally dried in the shell, so they need to be dried only to a moisture content of 9 percent, as the shells will absorb enough moisture to bring the peanuts' moisture content to the desired 7 percent. The peanuts can be dried either in sacks or bulk bins at air temperatures of 120°F. Alternately, the peanuts can be dried in a continuous dryer with air temperatures of 85 to 90°F.

5. Seed Cotton: The cotton seeds are first dried along with the cotton, as cotton needs to be dried to a 5 percent moisture content before it is ginned. This drying of the cotton is generally sufficient to bring the moisture content of the cotton seeds to the desired 11 percent moisture content. At present, seed cotton is dried in a vertical baffled dryer which operates at an air temperature of 150 to 160°F. This drying takes anywhere from 15 seconds to 3 minutes. After the cotton has been dried to 5 percent moisture content, the seed cotton is separated into cotton and seeds by ginning.

Depending on the weather conditions, drying the seeds with the cotton may not be sufficient to bring the moisture content of the seeds to the desired 11 percent. In such cases a vertical, continuous-flow dryer is used. The dryer operates at 220°F in the drying section and cools the seed to within 15°F of atmospheric temperature in the cooling section. The cost of drying cotton seeds using this method is high because during many seasons the dryer is not needed.

6. Sorghum: In most areas where sorghum is grown--notably Kansas, Texas, and Nebraska--it does not need to be dried. About 82 percent of the sorghum grown in 1974 and 1975 was grown in these three states. In addition 11 percent is grown in the dry southwestern and plains states. However, when grown in a more humid climate, as in the corn belt, sorghum does need to be dried. It is dried much like corn with a forced-air system at temperatures no greater than 140°F (grain temperature).

7. Barley: This crop is normally field dried, except when weather is unusually wet during the harvest season.

Vegetables.

1. Potatoes: The initial moisture content of potatoes is about 80 percent. After dehydration the potatoes have a moisture content of 6 to 8 percent. Annually, 6 to 8 percent of the total U. S. potato crop is dehydrated. In 1970 the United States produced 365 million pounds of dehydrated potatoes. Potato dice are generally dehydrated in continuous-belt dryers.

Before dehydration is started, the potatoes must first be blanched (heated in 212°F water or steam for 2-12 minutes) in order to kill harmful enzymes that could cause the potatoes to spoil. After blanching, the drying process is started at 275°F and gradually decreased over 1 hour to 175°F. The drying process is then completed in two stages. In the first stage the potatoes are dried at a temperature of 140 to 160°F. The final drying step is completed in bins at temperatures from 100 to 140°F. Substantially different processes are used to produce potato granules, flakes, and starch.

Before being dehydrated, potatoes can be stored for up to 10 months at a storage temperature of 38 to 40°F. With a harvest season of 2 to 3 months, potatoes can be dehydrated virtually 12 months of the year. However, potatoes that have been held at cold-storage temperatures are more suitable for dehydration if they are first conditioned. Conditioning the potatoes consists of holding them at 65 to 70°F for 1 to 3 weeks. This treatment allows the sugar (which has accumulated in the living tuber at the lower temperatures) to be reduced by natural respiration. (High-sugar potatoes are susceptible to discoloration during dehydration and subsequent storage.)

2. Onions: Onions have an initial moisture content of 88 percent and after dehydration contain less than 4 percent moisture. In 1970, 86.5 million pounds of dried onions were produced. Annually about 20 to 25 percent of the year's crop is dehydrated.

Onions are generally dried on a continuous-belt dehydrator with the drying proceeding in three stages. In the first stage the onions are dried at 160°F, and in the second stage at 130 to 140°F. In 10 to 15 hours, the onions are thus dried to a 5 to 7 percent moisture content. Their final moisture content of less than 4 percent is achieved in ventilated bins with 120°F dry air blown over the onions.

Before dehydration, onions can be stored for about 1 month in common storage (room temperature), or 6 to 8 months at 32°F. In many regions onions are harvested from May to October which, coupled with a 6 to 8 month storage limit, indicates that onions, too, can be dehydrated throughout the year.

3. Garlic: The initial moisture content of garlic is about 62 percent and after dehydration it is about 6.5 percent. In 1970, 21.9 million pounds (dry weight) of garlic was produced. Annually about 90 percent of the U. S. crop is dehydrated. The dehydration of garlic generally occurs on continuous belt dehydrators in two stages. In the first stage, drying is started at 180°F; this is gradually decreased to 130°F. The final stage of drying is done at 120°F until the moisture content of the garlic is 6.5 percent.

Nearly all of the U.S. garlic crop is grown in California, where it is harvested from May to August. Since it stores well under a variety of temperatures, it can be dehydrated 6 months of the year.

4. Chili peppers: Chili peppers initially contain 92 percent moisture and are dehydrated to a final 3 percent moisture content. The peppers are grown mainly in California and New Mexico. Almost all chili peppers grown are dehydrated. In fact, a California crop report includes only those chili peppers that are dehydrated, since the quantity of those that are not dried is insignificant. In 1974 California alone produced 10,200 tons of dried chili peppers.

Chili peppers used to be primarily sun-dried, but since sun drying takes several weeks, most chili peppers are currently dried in commercial dehydrators. A two-stage tunnel drying system is often used to dry the peppers. In the first stage the peppers are dried to a 20 percent moisture content, and in the second stage they are dried to their final 3 percent content. The drying temperature for chili peppers should not exceed 150°F.

5. Carrots and celery: Perhaps three or four California dehydrators process these vegetables. Diced or sliced carrots are dried from an initial moisture content of 88 percent to a final 4 percent in tunnel or continuous-conveyor dryers. Tunnel drying at about 160°F requires about 7 hours; the partially dried carrots are then transferred to drying bins with an inlet air temperature of about 140°F for about 7 hours of final drying. Drying time may be reduced to as little as 50 minutes in the newer continous-conveyor dryers.

Celery may be dried from 95 percent to 4 percent moisture content in two-stage tunnel dryers. Initial air temperature is about 180°F in the first stage and 130°F in the second.

Fruits.

1. Prunes: Prunes have an initial moisture content of 85 percent and are dried to a final 16 to 19 percent moisture content. Almost all prunes that are grown in the United States are dehydrated.[2] In 1974, about 154,000 tons of prunes were dried (wet basis). This represents approximately 88 percent of the total U.S. crop.[16] The prunes are generally dehydrated in a forced-draft tunnel dehydrator. Drying begins at a temperature of no more than 165°F. Drying is completed at a final stage temperature which is 15°F lower than that in the first stage.

2. Apples: With an initial moisture content of 85 percent, apples are dehydrated to a final 18 to 20 percent moisture content.[2] Since 1967 a constant 3 percent of the United States apple crop has been dried.[1] This 3 percent is dried in only two states, Washington and California: Washington dries 6 percent of its crop and California dries 14 percent.[14]

Although apples were sun-dried in the past, at present almost all apples are dried in commercial dehydrators.[17] One method for drying apples is to use an air-blast tunnel dehydrator. When dried in this way, apples begin drying at 165°F at the hot end of the tunnel. This initial temperature is reduced by 60 percent at the cool end of the tunnel.[2] The lower the finishing temperature, the less danger of the apples turning a brown color or of the sugar in them caramelizing. The drying time using this method is approximately 6 hours.[6] A second method for dehydrating apples is through the use of a kiln. By using this method, apples are dried in a kiln that operates at 135°F.

3. Apricots, peaches, pears: These three fruit crops are almost exclusively sun-dried. However, at least one California dehydrator processes small amounts of these cut fruits artificially. The dehydration process is similar: after the fruits are halved and pitted, they are sulfured and then dehydrated. Apricots are dried for about 8 hours at a maximum temperature of 150°F to 18 percent moisture content. Peaches are dried in a countercurrent tunnel and a maximum air temperature of 155°F for 24 to 30 hours; the final moisture content is about 25-28 percent. Pears are dried in a similar manner except that drying time may vary from 6 to 48 hours.[2]

4. Grapes (raisins): About 7 percent of total U.S. raisin production, or 15,000 tons, are dried artificially. About 95 percent of these are prepared as golden-bleach raisins. All raisin dehydration is in California at present. The grapes to be processed are spread on trays and exposed to sulfur fumes for about 4 hours. Then the trays are moved to tunnel dehydrators for 24 to 45 hours until the final moisture content, 10-14 percent, is achieved.[2]

Livestock Commodities.

1. Milk: Milk has an initial moisture content of 87 to 90 percent and is dehydrated to a final 5 percent moisture content. About 3 billion pounds of dried milk are made each year, which is about 20 percent of the total milk production of the United States. As milk is produced throughout the year, it can, of course, be dehydrated all year. Dehydrated milk is produced almost exclusively by spray drying with the drying-air temperature at a maximum of 150 to 160°F.[2]

2. Eggs: The initial moisture content of the whole egg is 74 percent, of egg white 88 percent, and of egg yolk 51 percent. All parts of the egg are dried to a final moisture content of less than 2 percent. In 1970, 75.3 million pounds of dried eggs were produced. Annually about 35 to 38 percent of the total egg production in the United States has been converted into dried eggs. As in the case of milk, eggs are produced year-round, allowing egg dehydration to occur 12 months of the year.

Eggs are also spray dried in the same manner as is milk. This spray drying occurs in two stages. The eggs are first spray dried at air temperatures above 138°F to prevent bacteria growth; then in the second stage, the air temperature is dropped to 85°F to complete the drying process.[2]

Common Types of Crop Dryers

Many types of dryers or dehydrators are used in processing the various commodities discussed in the previous sections. The following is a brief description of each type of heat-processing equipment which is used in drying/dehydrating crops.

Forced-air dryer. This is a broad classification for any type of crop dryer that uses the movement of air to transfer heat to the crop and to carry away the moisture that has evaporated.[2]

Continuous-flow dryer. The continuous-flow dryer is a type of forced-air dryer that is generally used for grain drying. In this dryer the grain is introduced at the top (or one end) of the dryer (depending on whether it is a vertical or horizontal system). As the grain flows through the first two thirds of the dryer length, it is heat-dried by forced air. The last one third of the dryer is devoted to the cooling of the grain. The amount of moisture removed can be controlled by the residence time in the dryer, which in turn is controlled by the grain flow rate.[2]

Bin dryers. Much bin drying relies on natural ventilation to dry the grain; however, forced-air drying is also used in bins. When forced air is used, the bins have either a perforated false floor or perforated ducts on the floor. A fan forces drying air under the false floor (or into the duct system) and through the grain (or other commodity). This method of drying is mainly used for commodities that contain only a few percentage points of excess moisture. Natural or slightly heated air is used.[4]

Continuous-belt dryers. This method of drying is used mainly for fruits and vegetables. The produce to be dried is loaded on the belt in the desired depth and moves through a heated chamber or chambers. The temperature at the entry end is warmer than the temperature near the exit end (parallel flow). The temperature to which the produce is exposed is determined by where the produce is in the dryer, and by which chamber the produce is in at the time. The moisture removed is controlled by the temperature throughout the dryer and by how long the produce remains in each of the chambers.

Tunnel dryers. A tunnel dryer is also used mainly for fruits and vegetables. A forced-air flow is used to dry the produce. The temperature used to dry the produce is determined by the temperature of the air blowing through the tunnel. Tunnel dryers generally have one to three stages (occasionally more), or times the temperature of the air blowing through the tunnel is altered. The moisture removed will be determined by the amount of time the produce is exposed to each of the different temperatures.[1]

Spray drying. Spray drying is a technique used on liquids in which the particles of the substance being dried move along in the air stream with the heated gas. One method of regulating the moisture content is by the use of redryers. The redryers are arranged in a series with the primary drying chamber drying the commodity to a predetermined moisture content. Removal from this stage causes the drying particles to be picked up by a secondary hot stream. Another way of regulating moisture content is to have the vapor pressure of the water associated with the particle surface approach the pressure of water vapor in the air at the point where the powder particles are removed from the exit air.[2]

Profile of Crops Grown Near Geothermal Resources.

In order to choose sites for multicrop drying centers, data was needed on the acreages near identified geothermal resources of the dryable crops. The best available source of such data that is consistent from state to state and that provides resolution at the county level is the 1969 Census of Agriculture.[18] Midwest Research Institute culled from this data base both acreage and production (number of harvested bushels, tons, etc.) figures for each of the 20 dryable crops, for each of the 275 Geothermal Counties (those counties all or part of which are within 50 miles of identified geothermal resources: see Chapter 4).

At the same time, similar statistics from the census were compiled for 17 crops that satisfied another criterion--that they be among the ten most valuable crops, on the basis of gross receipts by farmers in 1975, in at least one of the 11 contiguous U.S. geothermal states. This data helps provide a first basis for defining potential sites for the alternative applications of geothermal heat outlined in Chapter 11.

The acreage figures for the dryable crops were used in raw form to select the crop combinations for MDCs and to evaluate whether the crop areas near the MDC sites were sufficient to permit commercial drying. The 1969 Census of Agriculture data were checked when possible against 1974 or 1975 county data from state agricultural statistics bulletins published by the state crop and livestock reporting services.

The census data were made to serve another purpose as well: they were aggregated in order to estimate, for each state, the total acreage and value of each of the 37 crops that was grown within 50 miles of the geothermal resources. These estimates provide state profiles of the frequency of occurrence and economic importance of each crop in geothermal areas. These profiles present comparisons of occurrence and value among crops in the geothermal areas of a given state and among states for a given crop. The state profiles also serve as backdrops against which the multicrop drying centers may be evaluated. Finally, they might also be used for a variety of other purposes: for example, to evaluate the potential for irrigation with geothermal water.

The method used to construct the crop acreage and value profiles for each state was straightforward. The 1969 census data for crop acreage and production were loaded into tape files and processed using BASIC-language computer codes with a portable mini-computer. The programs weighted individual county figures with a factor equal to the area of the county that is within 50 miles of a U.S.G.S. identified geothermal resource[19] divided by the total county surface area. (It should be noted that this weighting procedure makes the assumption that a crop is distributed homogeneously throughout a county; when a county is large or varies widely in terrain, altitude or soils--all unknowns here--significant error at the county level is to be expected.) These individual estimates of crop acreage or production for all Geothermal Counties in each state were then summed. The state estimates for crop acreages within 50 miles of the resources were completed with this step.. The production estimates for each state, however, were multiplied by the unit prices[20] received by farmers in that state to arrive at the estimates for total crop values within 50 miles of identified geothermal resources.

Table 10.4 shows the number of geothermal counties that grow each of the 37 crops in relation to the total number of Geothermal Counties in each state. It provides an indication of whether the crop acreages and values shown in Tables 10.5 and 10.6, respectively, are concentrated in just a few counties or distributed among many. Finally, Figures 10.1 and 10.2 present the crop area and value estimates for the area within 50 miles of geothermal resources of the entire continental United States.

Figure 10.1 shows that alfalfa hay (not to be confused with dehy), barley, and wheat are clearly the most frequently occurring crops grown in the geothermal areas. Together they account for 61 percent of the total acreage of the 37 crops within 50 miles of identified resources; alfalfa alone accounts for 29 percent of acreage. The 10 most common crops account for 87 percent of the 9.1 million crop acres.

In dollar value terms, a different and less-concentrated picture of the top-ranked crops emerges. The three most valuable crops--alfalfa hay, Irish potatoes and tomatoes--represent only 33 percent of the total 37-crop value within 50 miles of geothermal, and alfalfa hay, 14 percent. The ten most valuable crops are worth 75 percent of the total $1.7 billion.

Profile of Present Drying Industries

This section presents a summary of data on present energy use by 12 crop-drying and dehydration industries. National energy use for drying and the portion of that use that takes place within 50 miles of identified geothermal resources have been estimated. The estimates are summarized in Table 10.7; state-by-state descriptions of the industries and estimates of energy use are found in Appendix C.

The estimates serve two main purposes. First, those for drying-energy use near geothermal resources provide first approximations of the maximum geothermal-retrofit potentials for these drying industries. They answer the question, "How much fossil energy could be saved by converting the drying industries to geothermal?" In so doing, the estimates can serve as targets against which to evaluate DOE policy for the drying industries or participation in specific demonstration projects. The estimates have been used for brief policy analyses in Chapter 12 of this report.

Second, a knowledge of the locations of crop-drying facilities is important to a detailed appraisal of multicrop drying centers. Sites for MDCs were chosen on the basis of limited information about crops--harvested acreages and production. The presence of nearby dehydrating facilities for one or more of the crops to be dried at an MDC would indicate that varieties of these crops that are suitable for dehydration are grown near the MDC site; this is important information. In addition, the existence of such dehydration plants would confirm that markets for the dried product and skilled labor to

Table 10.4

DISTRIBUTION OF CROPS NEAR GEOTHERMAL SOURCES AMONG THE GEOTHERMAL STATES

Crop Growing Near Geothermal Source[1] / Geothermal State	ARIZONA	CALIFORNIA	COLORADO	IDAHO	MONTANA	NEVADA	NEW MEXICO	OREGON	UTAH	WASHINGTON	WYOMING
GRAINS											
Barley	7/11	41/56	33/47	36/38	16/17	11/16	11/18	25/26	21/23	10/20	3/3
Corn	5/11	26/56	16/47	16/38		1/16- 6/16[4]	7/18	9/26	6/23- 22/23[4]	6/20	
Oats					15/17						3/3
Rice		15/56		2/28							
Ryegrass								21/26			
Sorghum	8/11	25/56	14/47	6/38		2/16	9/18	3/26	4/23	1/20	
Wheat	10/11	43/56	41/47		16/17	13/16	18/18	26/26	23/23	14/20	2/3
FRUITS											
Apples		23/56	7/47	7/38			8/18	9/26	4/23	7/20	
Apricots		21/56	3/47					1/26	2/23	4/20	
Cantaloupes	2/11[2]										
Grapes	2/11	30/56		1/38				3/26		2/20	
Oranges		18/56									
Peaches	3/11	23/56	4/47	4/38				9/26	4/23	5/20	
Pears		25/56	2/47	2/38				7/26	1/23	7/20	
Plums & Prunes	3/11	32/56	1/47	5/38				8/26		1/20	
Sweet cherries					1/17			17/26			
VEGETABLES											
Carrots	1/11	11/56	2/47					7/26		4/20	
Celery		7/56								1/20	
Dry Beans			18/47	12/38[3]							
Dry onions	1/11	15/56	6/47	5/38		2/16	2/18	3/26	4/23	1/20	
Green Peas										8/20	
Hot peppers	1/11	10/56	1/47				5/18				
Irish potatoes	5/11	18/56	10/47	29/38	7/17	2/16	1/18	13/26	11/23	7/20	1/3
Lettuce	4/11	23/56					6/18				
Peanuts		1/56									
Snap Beans								9/26			
Sugar Beets	2/11	29/56	12/47	22/38	2/17				9/23	2/20	
Sweet potatoes		7/56									
Tomatoes		28/56				1/16	2/18	1/26	1/23	1/20	
OTHER CROPS											
Alfalfa Hay	11/11	49/56	37/47	38/38	17/17	15/16	17/18	26/26	22/23	19/20	3/3
Alfalfa seed				20/38		8/16			10/23		
Cotton		11/56				1/16	6/18		1/23		
Flaxseed		1/56									
Garlic		7/56									
Hops										1/20[5]	
Pecans							4/18				
Peppermint								10/26			
Safflower	2/11										

[1] In order to appear in this table, the crop must satisfy two criteria: (1) It must be in a county within 50 miles of a geothermal resource. (2) It must either be among the top ten crops by value of production in 1975 for one or more geothermal states or it must typically be dried as a step in processing for market.

[2] The county data (to determine proximity) combines cantaloupes, persians and muskmelons.

[3] Includes garden seedbeans, which is also a top ten crop in Idaho.

[4] Corn for silage.

[5] Washington reports only one geothermal county for hops, but this represents 94% of the crop.

Legend: The fractions in each box indicate the number of geothermal counties growing the crop over the number of geothermal counties in the state.

U.S. Bureau of the Census, Census of Agriculture, 1969: Volume I, Area Reports (Washington, D.C.: U.S. Government Printing Office, May, 1972) and statistical crop reports published by each of the states.

Table 10.5

1969 HARVESTED CROP ACREAGES WITHIN 50 MILES OF GEOTHERMAL RESOURCES IN RELATION TO STATE ACREAGES

	AZ	CA	CO	ID	MT	NV	NM	OR	UT	WA	WY
GRAINS Barley*	66/132	589/989	119/253	473/659	100/1523	16/18	3/12	225/357	70/117	12/340	7/11[illegible]
Corn* (grain)	2/5	80/59	18/308	25/25	0/5	1/ND	1/11	5/7	3/5	8/29	0/20
Oats					22/342						0/75
Rice*		329/381		12/ND							
Ryegrass								6/7			0/9
Sorghum*	68/158	171/282	22/255	1/1	0/7	<1/<1	20/264	<1/1	<1/1	<1/1	0/1
Wheat	17/59	251/404	155/1803		192/3670	11/11	4/149	489/734	115/220	32/2273	1/236
FRUITS Apples*	0/<1	14/25	5/7	6/7	0/<1	0/<1	1/4	6/7	2/8	46/92	0/<1
Apricots*	0/<1	19/34	1/ND					<1/<1	0/<1	0/1	
Cantaloupes	2/17										
Grapes*	2/6	258/458		<1/<1				19/ND		4/10	
Oranges		121/195									
Peaches*	<1/1	124/ND	1/3	1/1			0/<1	2/2	1/2	2/4	
Pears*	0/<1	29/43	<1/1	<1/<1			0/<1	14/21	1/1	13/22	
Plums and Prunes*	<1/<1	89/129	<1/<1	3/4				2/11	0/<1	1/3	
Sweet Cherries					0/<1			10/18		5/11	
VEGETABLES Carrots*	1/3	15/22	0/1					2/2	0/<1	1/2	
Celery*		8/16								0/<1	

Table 10.5 (Cont.)

	AZ	CA	CO	ID	MT	NV	NM	OR	UT	WA	WY
Dry beans			46/209	111/113	0/1						0/30
Dry Onions*	1/2	13/20	4/5	4/4		0/< 1	3/3	6/7	1/1	0/1	
Green Peas										41/83	
Hot Peppers*	0/1	2/3	0/<1				2/3				
Irish Potatoes*	6/12	38/77	34/47	240/272	2/7	1/1	<1/2	39/46	4/6	5/63	<1/3
Lettuce	16/50	100/142					5/7				
Peanuts*	0/1	<1/1					0/7				
Snap Beans				1/1				18/28			
Sugar Beets	13/27	197/270	19/183	162/172	2/64				20/29	9/56	0/65
Sweet Potatoes		6/7					0/<1				
Tomatoes	0/1	147/176	0/1	0/< 1		1/ND	0/1	0/<1	0/2	0/1	
OTHER CROPS Alfalfa*Hay	61/158	640/988	211/673	799/903	260/1092	136/160	21/154	284/343	194/358	45/441	19/436
Alfalfa Seed				31/33		19/19			14/20		
Cotton*	78/293	327/664				1/2	52/136		1/ND		
Flaxseed*		2/3			0/10						
Garlic*		3/5									
Hops										10/17	
Pecans							6/8				
Peppermint oil								29/37			
Safflower	10/20										

Key: Estimated 1969 crop acreages within 50 miles of identified geothermal resources are in numerators; total acreages (all counties) are in denominators.[19] Figures show thousands of acres; absence of figure indicates no recorded crop in state.

*indicates dryable crop. ND = no data

Table 10.6

1969 HARVESTED CROP VALUES WITHIN 50 MILES OF GEOTHERMAL RESOURCES IN RELATION TO STATE VALUES

	AZ	CA	CO	ID	MT	NV	NM	OR	UT	WA	WY
GRAINS Barley*	6/11	35/58	6/11	24/33	4/46	1/1	<1/1	8/15	4/7	1/14	<1/5
Corn* (grain)	<1/<1	11/21	2/36	3/3	<1/<1	<1/ND	<1/<1	1/1	<1/<1	1/4	0/2
Oats					<1/9						0/2
Rice*		89/102		3/ND							
Ryegrass								<1/<1			0/<1
Sorghum*	4/16	17/26	<1/10	<1/<1	0/<1	<1/<1	2/15	<1/<1	<1/<1	<1/<1	0/<1
Wheat	1/5	16/22	4/42		7/114	1/1	<1/4	23/34	4/8	1/107	<1/5
FRUITS Apples*	0/<1	5/14	2/3	4/5	0/<1	0/<1	<1/1	4/4	1/1	24/47	0/<1
Apricots*	0/6	15/28	<1/<1					<1/ND	0/<1	0/1	
Cantaloupes	2/13										
Grapes*	2/5	105/194		<1/<1				<1/<1		3/7	
Oranges		86/145									
Peaches*	<1/<1	43/90	1/2	<1/1			0/<1	<1/1	<1/<1	1/1	
Pears*	0/<1	24/35	<1/1	<1/<1			0/<1	2/17	<1/<1	7/11	
Plums and Prunes*	<1/<1	39/55	<1/<1	2/2				<1/2	0/<1	2/3	
Sweet Cherries					0/<1			0/8		0/7	
VEGETABLES Carrots*	1/2	24/36	0/1					2/2	0/<1	1/2	
Celery*		23/44								0/<1	

Table 10.6 (Cont.)

	AZ	CA	CO	ID	MT	NV	NM	OR	UT	WA	WY
Dry beans			3/14	16/16	0/15						0/3
Dry Onions*	1/2	13/19	1/7	8/8		0/1	3/4	12/13	1/1	0/3	
Green Peas										6/12	
Hot Peppers*	0/1	4/6	0/<1				1/2				
Irish Potatoes*	4/8	27/55	13/18	96/108	2/4	<1/<1	<1/1	22/26	2/3	2/35	<1/2
Lettuce	22/70	99/141					5/7				
Peanuts*	0/<1	<1/<1					0/1				
Snap Beans				1/1				10/15			
Sugar Beets	3/6	55/77	5/47	44/46	<1/17				5/8	3/21	0/19
Sweet Potatoes		6/8					0/<1				
Tomatoes	0/<1	150/179	0/1	0/<1		1/ND	0/<1	0/<1	0/1	0/1	
OTHER CROPS Alfalfa*Hay	9/23	96/152	13/46	57/63	15/55	13/15	3/19	23/28	16/28	4/40	1/20
Alfalfa Seed				4/5		3/3			1/1		
Cotton*	19/79	83/165				<1/<1	8/22		4/ND		
Flaxseed*		<1/<1			0/<1						
Garlic*		3/5									
Hops										8/13	
Pecans							1/2				
Peppermint oil								9/11			
Safflower	3/16										

Key: Estimated 1969 crop values within 50 miles of identified geothermal resources are in numerators; total values (all counties) are in denominators.[19] Figures show millions of dollars; absence of figure indicates no recorded crop in state.

*indicates dryable crop. ND = no data

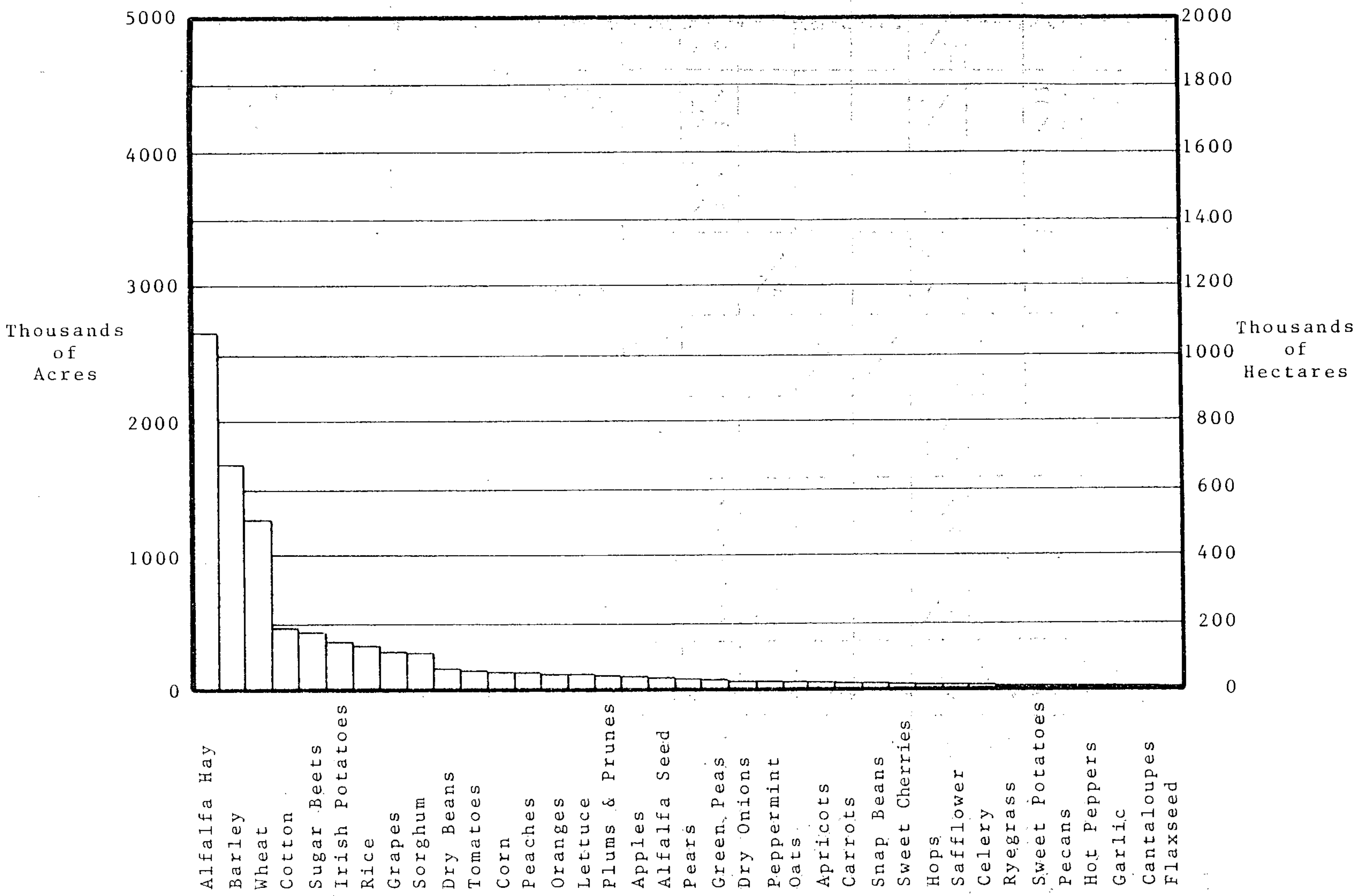

Figure 10.1. 1969 Continental U.S. Crop Acreages $\leq$ 50 Miles from Identified Hydrothermal Systems with Estimated Subsurface Temperatures Greater than 90° C.

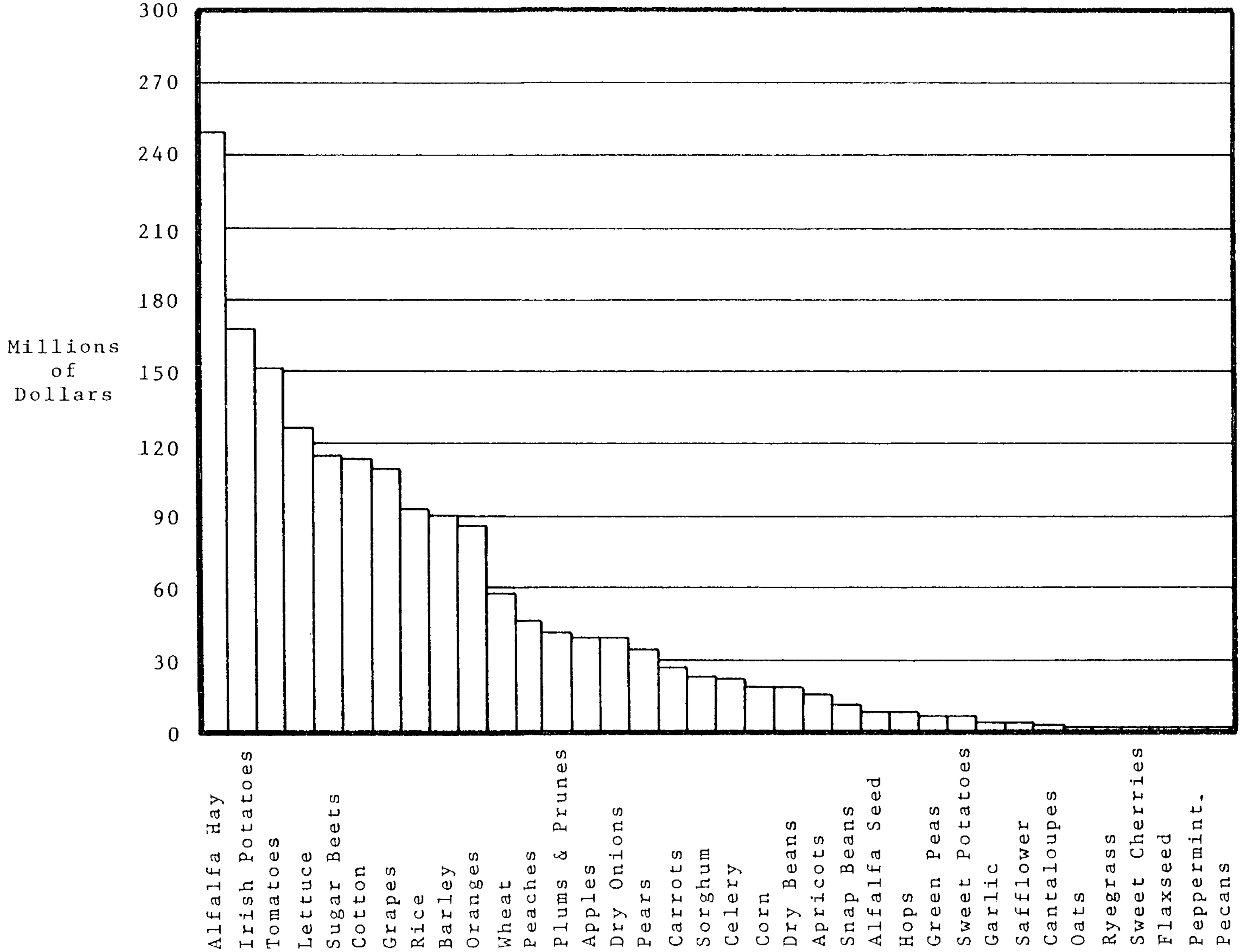

Figure 10.2. 1969 Continental U.S. Crop Values in Areas ≤ 50 Miles From Identified Hydrothermal Systems with Estimated Subsurface Temperatures Greater than 90° C.

Table 10.7

SUMMARY OF ENERGY USE BY DEHYDRATING INDUSTRIES
WITHIN 50 MILES OF GEOTHERMAL RESOURCES
AND IN WHOLE UNITED STATES

Drying Industry	Description and Location	Estimated Annual Drying Energy Consumed, 1976		
		Total U.S.	≤50 miles from GT	
		10^9 Btu's	10^9 Btu's	% U.S.
Sugar beet pulp dehydration	Dried byproduct of beet sugar production used as feed ingredient; AZ, CA, CO, ID, MT, OR, UT, WA, WY; KS, MI, MN, NB, ND, OH, TX.	32,000	9,700	30%
Alfalfa dehydration	Artificially dried alfalfa hay sold as feed ingredient. Main concentration is in KS, NB; geothermal states: AZ, CA, CO, ID, MN; 15 other states.	15,000	1,400	9%
Potato dehydration	Dehydrated granules, flakes, slice, dice and starch plants included; potato chip and frozen products excluded. CO, ID (concentration), NV, OR, WA, WY; also MN, NY, MI, ND, MN.	7,300	4,700	64%
Cotton ginning	Heat usually required to reduce moisture of raw cotton; AZ, CA (large), NV, NM; also TX (large), 12 other states.	3,500	490	14%
Onion dehydration	Sliced, chopped, minced, granulated and powdered, dried onion is mostly an input to other processed foods like catsup and chili sauce; CA only.	1,500	1,000	67%
Prune dehydration	Nearly all prunes are artificially dried, mostly in CA, small amounts in OR, WA.	1,300	1,200	92%
Rice drying	Drying is required before milling; CA produces a large amount of rice; TX, LA AR, are large producers, some in MS and MO.	1,300	250	19%
Apple dehydration	Sliced or diced artificially dehydrated apples; CA and WA are the large producers; NY produces smaller amount.	630	340	54%
Chili and other vegetable dehydration	Chili is largest component, but carrots, tomato powder, bell peppers and at least 15 others dried in small amounts; CA, NM (large), WA; also LA, NC (sweet potatoes).	400	310	78%

Table 10.7 (Cont.)

Drying Industry	Description and Location	Estimated Annual Drying Energy Consumed, 1976		
		Total U.S.	≤50 miles from GT	
		10^9 Btu's	10^9 Btu's	% U.S.
Garlic dehydration	Mostly sold as powder or granules, dried garlic is retailed and used in canned dog food and other prepared foods; CA only	300	250	83%
Raisin dehydration	Some grapes are dried artificially as the "golden bleached" variety; CA only.	300	100	33%
Peach, pear, apricot dehydration	Some prune, raisin and apple dehydrators produce small amounts, but mostly sun-dried; CA, WA.	17	9	53%
Total	12 drying industries	64,000	20,000	31%

run new drying facilities were available locally. Finally, the present drying industries near an MDC site are the most likely participants in a joint-venture geothermal drying facility; they are a group to which this report is specifically addressed. Thus, this section and Appendix C are intended to awaken recognition among crop and food dehydrators of the MDC and geothermal-retrofit alternatives.

Much of the data gathered were responses to telephone requests to drying companies for information about their present energy use for drying. Every effort was made to exclude the energy use for space heating of buildings and auxiliaries associated with the drying plants.

Energy consumption figures for individual plants were gathered by telephone for the alfalfa, potato, rice, and apple drying industries; for the sugar-beet pulp, cotton, prune, and raisin drying industries, good production estimates were possible, and energy use per unit production was taken as a constant; for the remaining industries more elaborate stratagems were required to estimate energy use. Full details on the methods of estimating energy use are provided in the references for Appendix C.

It will be noted that several of the dried crops discussed in a previous section of this chapter do not appear among the drying industries in Table 10.7. Several of these crops were found to be almost always field-dried in the West: sorghum, barley, and most corn. Some artificial corn drying appears to be done in central Washington[21] and in Cochise County in Arizona.[22] Small quantities of peanuts (none in areas within 50 miles of geothermal resources) are grown in Arizona, California, and New Mexico; apparently artificial dehydration is not required in these dry states as it is in the South.

Insufficient production data were gathered to make energy use estimates for dairy-product (milk and egg) dehydration. However, the plant location information that is available[23] shows one plant in Tempe, Arizona, about 15 miles from the Power Ranch Wells resource; 15 plants in California (7 less than 50 miles from resources); a plant in each of Caldwell and Idaho Falls, Idaho, both near resources; 2 plants in Oregon, the one in Portland within 50 miles; a plant in Ogden, Utah about 12 miles northeast of Hooper Hot Springs; 2 plants in Washington, the Lynden plant being about 40 miles from Baker Hot Springs; and a dried cheese-food plant in Afton, Wyoming. The principal dried products of the plants near geothermal resources are nonfat dry milk (spray process), dry whole milk, and dry buttermilk.

Table 10.7 indicates that geothermal retrofitting of five industries could save 90 percent of the 2.0×10^{13} Btu's of fossil fuel that are consumed annually for crop drying by plants within 50 miles of identified geothermal resources, and belonging to the 12 industries studied. Sugar-beet pulp dehydration alone consumes 9.7×10^{12} Btu's; this estimate assumes that all sugar-beet pulp is dehydrated. The feasibility of using geothermal heat for sugar refining was the subject of another study, which concluded that beet pulp drying with geothermal heat appears to offer an opportunity for saving 30 to 50 percent of total sugar-factory fuel use. Rotary drum dryers of the sort used to dehydrate alfalfa were selected for economic analysis of beet-pulp drying. This analysis concluded that these dryers would be only marginally economical were they to be used independently. However, if the geothermal brine were first cascaded through a low-pressure steam boiler and then through the dryers to dehydrate beet pulp for four months and alfalfa for a further six months, the cost per million Btu's might drop as low as $1.27 when brine temperature is 350°F. The study indicates that sugar factory operators have expressed interest in retrofitting present factories where geothermal energy is readily available.[24]

Potato dehydration to produce granules, flakes, slices, dices and starch appears to offer excellent potential for geothermal retrofitting; nearly 5×10^{12} Btu's is used annually by plants within 50 miles of identified geothermal resources. Fifteen plants are located in the Snake River Valley of Idaho alone; only 2 of these are more than 50 miles from identified resources. A simple policy analysis of geothermal potato dehydration is contained in Chapter 12.

Since potatoes can be stored for up to 10 months, they can be processed virtually year-round. Geothermal-energy system utilization over time could thus be very high. While detailed consideration of the technical feasibility and economics of retrofitting specific potato dehydration processes is beyond the scope of this chapter, it appears that most of the commonly used processes could be retrofitted with geothermal water-to-air heat exchangers. In the case of the potato-flake and starch processes, flashed steam at about 75-80 pounds per square inch would be required.[2]

After alfalfa dehydration, prune drying ranks fourth in the potential fossil-energy saving that geothermal retrofitting might provide. Most of the U.S. prune dehydration is conducted in the Sacramento Valley of California. While all but one of the 15 largest dryers are within 50 miles of an identified resource, the typical plant might be located 30-60 miles to the east or south. More study is required to determine whether significant numbers of prune dehydrators could move close enough to utilize geothermal energy while retaining their supply base of raw prunes. Retrofitting of the forced-draft tunnel dryers with geothermal heat exchangers is unlikely to present technical problems. However, prunes appear to be dehydrated for a maximum of about two months, during and immediately after harvesting; it is not likely that a geothermal energy system dedicated solely to a prune dehydrator would be utilized enough to be economic.

Geothermal retrofitting of onion dehydration plants could save an estimated 1.0×10^{12} Btu's of fossil fuel annually, all of it in California. Four plants were identified within 50 miles of geothermal resources: one in Vacaville (Solano County), two in Gilroy (Santa Clara County) and one in Dos Palos (Merced County). The Vacaville plant is only about 10-15 miles east of (Jackson's) Napa Soda Spring, which has an estimated subsurface temperature of 150°C. The Gilroy plants are approximately 10 miles south of a 45°C (surface) hot spring; the Dos Palos plant is about 20 miles northeast of Mercey Hot Springs (125°C subsurface).

Like potatoes, onions can be stored for lengthy periods and thus dehydrated all year: capacity utilization of a geothermal energy system should be high. The multistage continuous-belt conveyor units used to dry onions require an air temperature of no more than 180°F,[2] so that both the Vacaville and

Dos Palos plants might well be able to utilize nearby geothermal resources (plant relocation might be required). More detailed study should be made of retrofitting these plants.

Selection and Evaluation of Multicrop Drying Centers

An overview of the concept and method of choosing and evaluating multicrop drying centers was provided in the introduction of this chapter. Table 10.8 outlines in detail the strategy that was employed to define the MDC sites. The crop-acreage statistics were drawn from the 1969 Census of Agriculture and supplemented whenever possible with 1974 or 1975 county production data from state agricultural statistics bulletins. Specific data on the locations of crop growing areas within counties was lacking for most states. However, fairly good estimates could be made with the aid of 1:500,000-scale state "Geothermal Land Classification Maps" (published by the U.S.G.S. Western Region Conservation Division, Office of the Area Geologist) and a map showing the status of soil surveys in the United States.[25] It was assumed that the probable growing areas would be level lands at the lower altitudes, especially river valleys, and that the soils in the important agricultural areas most probably would have been mapped. The locations of geothermal resources with respect to roads and railroads were also found on the state geothermal maps. Only resources identified in U.S.G.S. Circular 726 or marked as KGRA's were evaluated as potential MDC sites. It should be noted that no definite minimum was set for the amount of each crop that would be required to make drying it in an MDC economic; this would require site-specific analysis. However, a qualitative judgment regarding the quantities of the crops in each MDC combination was made; this judgment entered into classifying the MDC sites into high, medium, and low potential groups.

Once the sites had been chosen and grouped by the agricultural and geographical criteria of Table 10.8, they were ranked using a figure of merit as shown in Table 10.9. How adequate the resource temperature is in relation to the crop drying temperatures, how efficiently the geothermal energy might be utilized, and how much fossil fuel is presently used for drying crops that are included in the combination--these are the variables that are assessed in the figure of merit.

The greatest weight was given to the adequacy of resource temperature, Parameter A; the U.S.G.S. "best estimate" for subsurface reservoir temperature was used. When no such estimate was available, a score of two was assigned, in effect giving the resource the "benefit of the doubt." A score of zero was not assigned unless it appeared that the resource temperature was too low to allow any of the proposed crops to be dried. Preliminary estimates of the geothermal water temperatures required to dry each crop are shown in Table 10.10; engineering studies should be performed to refine them.

Parameter B factors into the figure of merit (FOM) the importance of a long annual operating season for an MDC. A crucial determinant of geothermal energy cost is, of course, the percent of utilization over time of the

Table 10.8

STRATEGY EMPLOYED TO DEFINE SITES
FOR MULTICROP DRYING CENTERS

1. In each state, identified most important Geothermal Counties for each dryable crop using acreage statistics; rank-ordered these "target counties" for each crop by acreage.

2. Identified counties that were high-ranked members of target-county sets for two or more crops; the counties so identified became the "supply-base" counties for MDCs.

3. Selected the geothermal resource that is both a) closest to the likely crop-growing areas of each supply-base county, or set of such counties that are adjacent; and b) on or close to (within five miles) a road or railroad. The MDC site was assumed to be located at this resource location.

4. Reviewed dryable-crop acreages of counties with probable growing areas within fifty miles of each MDC site. Sometimes this resulted in the addition of new crops to the combination of crops to be dried; sometimes the MDC site was relocated to another resource more central to the dryable-crop growing areas; in this case, step 4 was reiterated.

5. Rank-ordered each preliminary MDC within each state on the basis of a) proximity of site to appropriate crop-growing areas; b) amount of production of each crop in the combination to be dried at the MDC; c) resource proximity to a road or railroad for raw material supply and product shipment.

6. Reviewed the preliminary MDCs in the set of all nine states for which MDCs were selected. Production figures for crops in the drying combination for each MDC were double-checked; some crops were dropped and some MDCs were eliminated because production appeared to be too small to support a drying operation. MDCs were also eliminated where they would compete with more favorable MDC sites for crop supplies.

7. Divided the successful MDCs into high, medium and low potential groups with the criteria of step 5; these are shown in Tables 10.11, 10.12, and 10.13, respectively.

Table 10.9

SCORING FOR PARAMETERS IN THE FIGURE OF MERIT
FOR MULTICROP DRYING CENTERS

Parameter	Description	Scoring	
A	What is Δt, where Δt equals the "best estimate" resource temperature, T, minus the highest drying temperature required, Dmax ? (Dmin is lowest required drying temperature of any crop.)	$\Delta T \geq 20°C$	= 3
		$0°C \leq \Delta t < 20°C$ or no data for T	= 2
		$T \geq Dmin-10°C$	= 1
		$T < Dmin-10°C$	= 0
B	How many months of the year could the MDC operate, given the drying seasons for the crops?	12 months	= 3
		9 to 12 months	= 2
		3 to 9 months	= 1
		less than 3 months	= 0
C	If cascading the waste heat from one drying process to those that require a lower temperature is conceptually possible,* what is C, where C = number of "cascade-months" divided by months of MDC operation?	$C \geq 1.0$	= 3
		$0.5 \leq C < 1.0$	= 2
		$0 < C < 0.5$	= 1
		Cascading impossible	= 0
D	What is the total annual United States use of fossil fuel for drying the crops that are included in the combination?	$>25 \times 10^{12}$ Btu's	= 3
		$10-25 \times 10^{12}$ Btu's	= 2
		$5-10 \times 10^{12}$ Btu's	= 1
		$<5 \times 10^{12}$ Btu's	= 0
E	Number of crops in the combination divided by two	(Not applicable)	

Figure of Merit = A [B + C + D] E

*See key, Appendix D

Table 10.10

CONCEPTUAL TEMPERATURE REQUIRED AT INPUT TO DRYING PROCESS FOR EACH CROP

Crop	Temperature (°C)*
Potatoes	140
Alfalfa	125
Sugarbeet pulp	125
Cotton	110
Garlic	90
Prunes	80
Raisins	80
Onions	75
Carrots	75
Peaches, pears	75
Chilies	70
Apples	65
Rice	60

*These temperatures are about 5°C above the maximum air temperatures required for the conventional drying processes; they give first approximations of the needed geothermal water temperatures for the processes.

geothermal system. The estimated length of the operating season for each MDC can be determined from Appendix D; it is simply the period during which at least one crop could be dried. The drying seasons for each crop in each MDC were approximated from the information about crop harvest seasons in Table 10.3, data on maximum storage time for each crop,[2] and information from existing drying plants.

Parameter C permits a conceptual evaluation to be made of how efficiently heat could be extracted from the geothermal water delivered to an MDC to dry the proposed crops. Full details of the concept of cascading the return flow from one drying process to the next are given in the key to Appendix D. Figures D.1, D.2 and D.3 show the conceptual drying cascades for each MDC. The number of "cascade-months" for each center gives a rough measure of the potential energy extraction over time; but time is already explicitly included in the FOM as Parameter A. Therefore, the number of cascade-months was divided by the length of the operating season to give the average number of cascades during MDC operation. This provides a crude index of how efficiently the available geothermal power is utilized.

Parameter D is scored according to the sum of the present fossil energy use in the United States for drying each of the crops that would be included in an MDC. Table 10.7 was used to provide this drying energy information. The intent of this parameter is to give extra weight to those MDCs that might be able to demonstrate use of geothermal energy in drying processes for which use of alternative energy sources potentially could save large amounts of fossil fuels.

Parameter E, which is simply the number of crops for which drying at an MDC is proposed weighted by a factor of .5, represents another qualitative judgment about MDC operation. All other things being equal, it is assumed that the more crops a center could dry, the higher its chances of successful operation would be. The markets and sources of supply for agricultural commodities are frequently unstable. Thus the more diverse MDCs should have the lower risks of failure; the number of crops to be dried serves here as a crude index of diversity.

Parameters A and E were given the greatest weight in calculating the figure of merit. Parameters B, C and D have roughly equal and smaller weights. For Parameters A, B, C, and D, the criteria attached to the four possible scores divide the range of values on which the score is based into four roughly equal groups. For example, roughly nine of the thirty-five MDCs could operate for twelve months, nine could operate for nine to twelve months, and so on. Thus an MDC that received a score of three for this parameter would lie in the upper quartile of operating-season lengths.

Tables 10.11, 10.12 and 10.13 show each multicrop drying center ranked by its figure of merit within the high, medium and low potential groups, respectively; also shown are the scores for each of the individual parameters. Table 10.14 summarizes the characteristics of the MDCs with the ten highest figures of merit, regardless of potential grouping. All of these ten appear to have associated geothermal resource temperatures more than adequate to dry all proposed crops. Seven could operate year-round; the remaining three would

Table 10.11

FIGURE OF MERIT FOR TEN HIGH POTENTIAL MULTICROP DRYING CENTERS

State	MDC	Resource Temperature*	Crop Combination	County Served	Scoring for Parameters of Figure of Merit					Figure of Merit
					A	B	C	D	E	
AZ	Power Ranch Wells	180°C	alfalfa, cotton, potatoes, onions, sugarbeet pulp, carrots	Maricopa, Pinal	3	3	3	3	3	81
CA	Brawley KGRA	200°C	alfalfa, cotton, onions, garlic, sugar-beet pulp	Imperial	3	3	3	3	2.5	67.5
CA	Surprise Valley KGRA	175°C	alfalfa, potatoes, onions	Modoc	3	3	3	2	1.5	36
CO	Alamosa County KGRA	No data	potatoes, alfalfa	Alamosa, Costilla, Rio Grande, Conejos	2	3	2	2	1	14
ID	Banbury Area	140°C	alfalfa, potatoes	Twin Falls, Jerome, Gooding	2	3	2	2	1	14
ID	NE Boise Thermal Area	125°C	alfalfa, potatoes, onions, apples, prunes	Ada, Canyon	1	3	3	3	2.5	22.5
ID	Weiser Area	160°C	alfalfa, apples, onions	Washington, Payette	3	3	2	2	1.5	31.5
NM	Radium Hot Springs KGRA	130°C	alfalfa, cotton, onions chilis	Dona Ana, Luna, Sierra	2	2	3	2	2	23
OR	Klamath Falls KGRA	120°C	alfalfa, potatoes	Klamath	1	3	0	2	1	5
OR	Vale H.S. KGRA	160°C	alfalfa, potatoes, onions	Malheur	3	3	3	2	1.5	36

*U.S.G.S. "best estimate."

Table 10.12

FIGURE OF MERIT FOR FIFTEEN MEDIUM POTENTIAL MULTICROP DRYING CENTERS

State	MDC	Resource Temperature *	Crop Combination	County Served	Scoring for Parameters of Figure of Merit					Figure of Merit
					A	B	C	D	E	
AZ	Mt. Graham Hot Mineral Well	110°C	cotton, alfalfa	Graham	1	2	0	2	1	4
CA	Arrowhead Hot Spring	150°C	alfalfa, apples, onions potatoes, carrots	San Bernardino, Riverside	2	3	3	2	2.5	40
CA	Ford Dry Lake KGRA	No data	onions, alfalfa, cotton	Riverside	2	3	3	2	1.5	24
CA	Los Guilicos Warm Springs	135°C	apples, prunes, raisins	Sonoma	3	1	2	0	1.5	13.5
CA	Mercey Hot Spring	125°C	alfalfa, cotton, rice, prunes, raisins	Merced, Fresno, Madera	2	2	2	2	2.5	30
CA	Pilger Estates Hot Spring	145°C	carrots, onions, alfalfa	Riverside, Imperial	3	3	3	2	1.5	36
CA	Napa Soda S. Rock (Priest)	145°C	prunes, raisins, alfalfa, rice, sugar-beet pulp	Napa, Yolo, Solano	3	2	3	3	2.5	60
CA	Wilber Hot Spring	145°C	rice, prunes	Colusa	3	0	1	0	1	3
ID	Ashton Warm Spring	145°C	alfalfa, potatoes	Fremont, Madison	2	3	2	2	1	14
ID	Mountain Home KGRA	135°C	alfalfa, potatoes	Elmore, Gooding	1	3	0	2	1	5
ID	Raft River KGRA	140°C	alfalfa, potatoes	Cassia, Minidonka	2	3	2	2	1	14
ID	Wayland Hot Spring	130°C	alfalfa, potatoes	Franklin, Bannock	1	3	0	2	1	5
MT	Barkel's (Silver Star) Hot Spring	145°C	alfalfa, potatoes	Madison, Jefferson, Gallatin	2	1	2	2	1	10
UT	Crystal Hot Springs	135°C	alfalfa, apples, sugar beet pulp, peaches, pears	Salt Lake, Utah	2	1	2	3	2	24
UT	Newcastle KGRA	No data	alfalfa, potatoes	Iron, Washington	2	3	1	2	1	12

*U.S.G.S. "best estimate"

Table 10.13

FIGURE OF MERIT FOR THIRTEEN LOW POTENTIAL MULTICROP DRYING CENTERS

State	MDC	Resource Temperature*	Crop Combination	County Served	Scoring for Parameters of Figure of Merit					Figure of Merit
					A	B	C	D	E	
AZ	Hookers Hot Spring	93°C	alfalfa, cotton, sugar-beet pulp, chilis	Cochise	1	2	1	3	2	12
CO	Orvis (Ridgeway) Hot Spring	110°C	alfalfa, apples, sugar-beet pulp, onions	Ouray, Montrose, Delta, San Juan	1	3	2	3	2	16
ID	Well near Brockie Airport	110°C	alfalfa, potatoes	Butte	0	(3)	(0)	(2)	(1)	0
ID	Castle Creek KGRA	145°C**	alfalfa, potatoes	Owyhee	2	3	2	2	1	14
ID	Roystone Hot Spring	150°C	alfalfa, apples, prunes	Gem, Payette	3	1	2	2	1.5	22.5
MT	Gregson Hot Spring	130°C	alfalfa, potatoes	Silver Bow, Deer Lodge, Powell	1	3	0	2	1	5
MT	Helena (Broadwater) Hot Spring	140°C	alfalfa, sugarbeet pulp	Lewis & Clark, Broadwater, Jefferson	2	1	1	3	1	10
NM	Lightning Dock KGRA	170°C	cotton, apples	Hidalgo, Grant	3	1	2	0	1	9
NM	San Ysidro KGRA	No data	alfalfa, apples	Sandoval, Santa Fe Bernalillo	2	1	1	2	1	8
NM	Socorro Peak KGRA	No data	alfalfa, cotton	Socorro	2	1	1	2	1	8
UT	Hooper's Hot Spring	105°C	alfalfa, onions, sugar-beet pulp	Weber, Davis	1	3	1	3	1.5	10.5
UT	Meadow Hot Spring	105°C	alfalfa, potatoes	Millard	0	(3)	(0)	(2)	1	0
WA	Ohanepecosh Hot Spring	130°C	alfalfa, potatoes, apples, pears/peaches, prunes	Yakima	1	3	1	2	2.5	15

*U.S.G.S. "best estimate"

**Temperature for Bruneau-Grandview area used.

Table 10.14

THE 10 MDCs WITH THE HIGHEST FIGURES OF MERIT (FOM)

MDC	Counties Served	State	Crops	FOM	Potential*
Power Ranch Wells	Maricopa Pinal	Arizona	alfalfa, cotton, potatoes, onions, sugarbeet pulp, carrots	81	H
Brawley KGRA	Imperial	California	alfalfa, cotton, onions, garlic, sugarbeet pulp	67.5	H
Napa Soda Spring (Rock, Priest)	Napa, Yolo, Solano	California	prunes, raisins, alfalfa, rice, sugarbeet pulp	60	M
Arrowhead Hot Spring	San Bernardino, Riverside	California	alfalfa, apples, onions, potatoes, carrots	40	M
Surprise Valley KGRA	Modoc	California	alfalfa, potatoes, onions	36	H
Vale Hot Springs KGRA	Malheur	Oregon	alfalfa, potatoes, onions	36	H
Pilger Estates Hot Spring	Riverside, Imperial	California	alfalfa, onions, carrots	36	M
Weiser area	Washington, Payette	Idaho	alfalfa, onions, apples	31.5	H
Mercey Hot Spring	Merced, Fresno, Madera	California	alfalfa, cotton, rice, prunes, raisins	30	M
Radium Hot Springs KGRA	Dona Ana, Luna, Sierra	New Mexico	alfalfa, cotton, onions, chilis	28	H

*H, M, and L indicate High, Medium and Low Potential grouping.

operate for nine to twelve months. Eight would have an operating-season average number of energy cascades of at least 1.0; the other two MDCs would have an average of more than 0.5. The maximum number of crops that would be processed at one of the ten top-ranked MDCs is six; the average number is 4.2; the minimum is three. Alfalfa is included in the crop combinations for all ten MDCs; onions are in eight; cotton and potatoes are each included at four; sugarbeet pulp and carrots are each at three; prunes, raisins, apples and rice are each at two; and garlic and chilies are each proposed crops at only one MDC. Six of the sites are in California; Arizona, Oregon, Idaho and New Mexico each have one. Finally, six of the sites are in the group of MDCs rated as "high-potential" on the basis of proximity to transportation and adequate nearby raw-crop supplies; the remainder are in the medium potential group.

A profile of a hypothetical "successful" multicrop drying center can thus be drawn. The MDC is in California and operates year-round, during which time it is usually able to process at least two crops. Alfalfa, onions, potatoes or cotton, and one other crop are dried. Raw-material supply is sufficient and within economic distance of the center; markets for the dried products are readily accessible by road and/or rail.

Obviously, the process used to evaluate the thirty-five multicrop drying centers that were defined provides only a basis for comparison among the sites; absolute judgments of technical and economic feasibility will require site-specific analyses. In addition to crop drying, other agricultural and space heating applications of geothermal heat might be included in broader "geothermal agriculture centers;" some of the alternatives are discussed in the next chapter. The intent of the foregoing analysis is to provide a "shopping list" of sites, within the narrower concept of geothermal crop drying, that may be useful to DOE policymakers and to the crop-drying industry. If this concept can be integrated into larger ones, so much the better.

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CHAPTER 11: ALTERNATIVE AGRICULTURAL USES FOR GEOTHERMAL HEAT

The drying of combinations of agricultural crops with geothermal heat at multicrop drying centers was the focus of the previous chapter. Drying and dehydration processes are not the sole uses in agriculture for low-temperature heat, of course. The purpose of this chapter is to outline some of the other present and potential agricultural processes to which low- and moderate-temperature geothermal resources might be applied; these might also be incorporated into synergistic processing centers, of course.

What constitutes an "agricultural process" is a difficult matter in this time of highly processed commodities, and so we will limit these suggestions to those activities that take place near farms or that could take place in a rural environment without penalty. Figure 11.1 is a tree or outline of heat-requiring processes for agricultural commodities. This schematic establishes an outside boundary for this chapter and provides a convenient framework for discussion. Each major section of the chapter expands on one of the boxes in the schematic.

Lignified Cellulosic Waste (IA 1)

Ruminant feed. Low-grade agricultural-roughage wastes, such as cereal straw, represent a vast supply of unused or poorly utilized energy; efforts to render it useful as a ruminant (cattle, sheep, etc.) feed have been underway for some time.[1] The degree of lignification of the cell walls is an important factor in digestibility, and so methods to make these wastes digestible have focused on delignification. Numerous chemicals have been tested for delignification but sodium hydroxide (NaOH) has proved to be the most useful alkali for mild treatment of cellulosic wastes.[2] Three basic methods show promise:

(1) Soaking with NaOH for over an hour at air temperatures.

(2) Soaking with heated NaOH at around 100°C for a few minutes.

(3) Pressurized-steam treatment with or without chemicals (sodium hydroxide or sodium metabisulfite). This treatment involves subjecting the material to steam pressures up to 28 kg/cm^2 (413 lb/in^2) for 50 seconds or so. The minimum temperature required to support steam at this pressure is around 212°C (440°F).

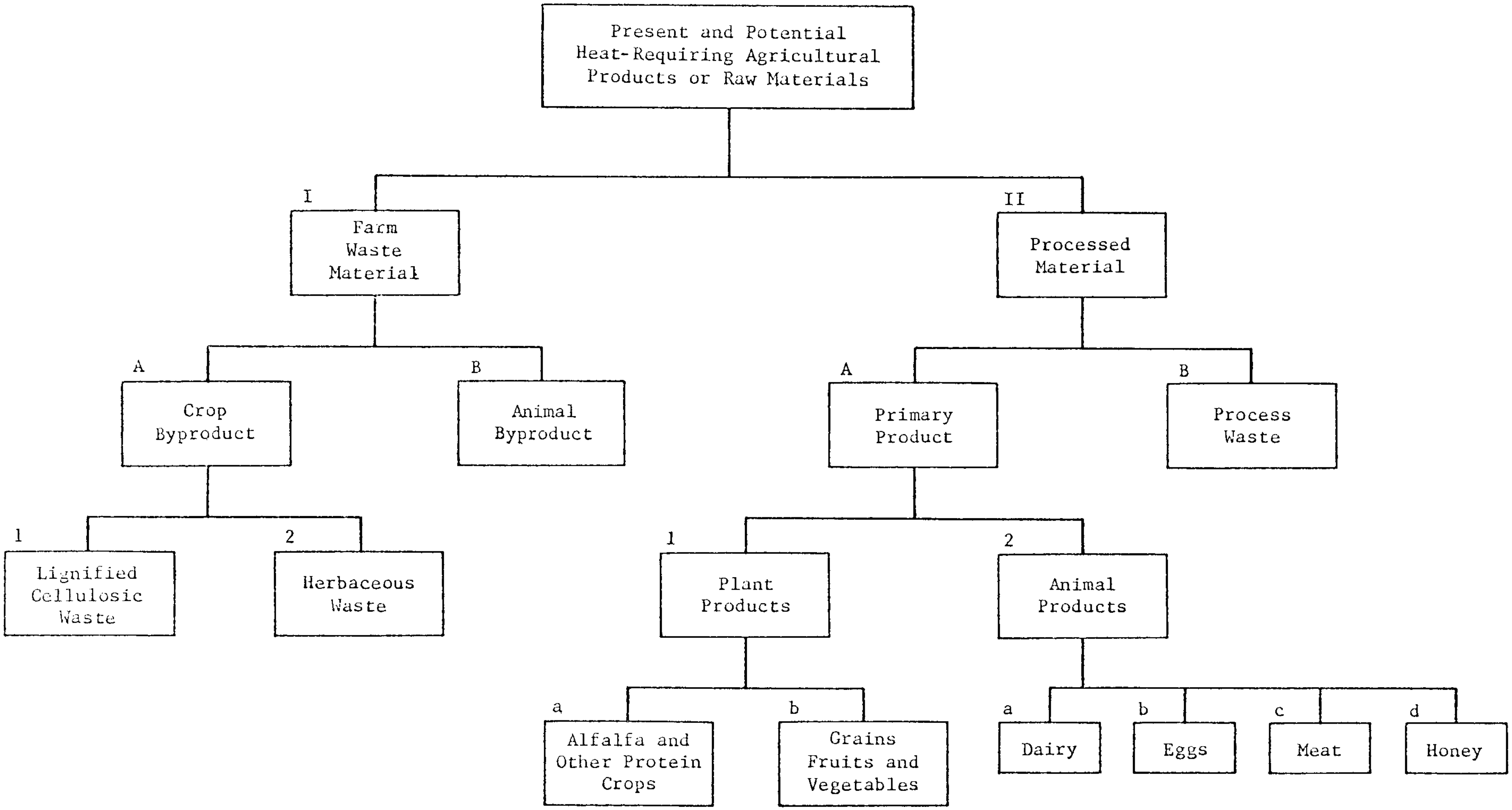


Figure 11.1. Heat-Requiring Processes for Agricultural Commodities

Process (3) may not be feasible with low-temperature geothermal heat,[3] but the milder alkali treatments, possibly followed by drying for storage purposes, theoretically could be used. George O. Kohler has performed research in this area and concludes:

> A variety of lignified cellulosic wastes like sugar cane bagasse and oilseed hulls accumulate at processing plants. Since no additional transportation costs are required to make these materials available for treatment, they represent a prime source of potential feedstuffs. Laboratory data show that excellent apparent-digestibility increases can be achieved by (heat) processing them with alkali. Even manure digestibility is greatly improved by alkali treatment.[4] Feed potential of these materials looks considerably brighter than that of sawdust, probably because the vegetable products have a relatively lower lignin content initially.[5]

Kohler points out that traditionally it has been cheaper to burn accumulated quantities of cereal straws, but that anti-air-pollution legislation makes it imperative to develop alternative disposal methods. He also states that simple plowing back into the soil is impossible with the perennial grass crops and is considered unsound and uneconomical by most rice farmers.[6] However, since these materials are found in relatively more dispersed form than hulls accumulating at processing plants, the costs of collection and transportation to geothermal sources would have to enter into the feasibility.

Examples of low-quality roughages that might be treated with alkali include

- cereal straws (rice, wheat, barley, corn cobs and stems)
- grass straw, alfalfa stems
- sugar cane bagasse, sorghum stems, milo stubble
- oilseed hulls

Of these kinds of crops, those that appear near geothermal sources in many states are

- cereal straws (wheat, corn, rice, barley)
- sorghum
- oilseed (flaxseed, safflower)
- alfalfa stems

Paper and paperboard. Although no wheat straw is used by pulping plants today, at least 30 pulping plants in the United States were buying this by-product at one time.[7] It is presently uneconomical to sell wheat straw to pulping plants, but this situation may change as the demands for both recreational forest land and timber products increasingly conflict. And as pointed out previously, stricter EPA guidelines prohibit burning of the straw, so that straws increasingly are becoming a burden to the farmer. Dwight Miller provides a forecast:

> Worldwide demand for paper and paperboard in 1985 is expected to be more than 250 million tons, as compared to current yearly demand of about 145 million tons. Although wood will predominate where available, the pendulum is expected to swing back toward agricultural fibers, which will become the world's raw material resource for paper in the future.[8]

About 3 percent of the total pulp and paper production in the United States uses nonwood raw materials, while a greater percentage of world production comes from cellulosic by-products.

Many crops could be used as raw materials. Examples include crop by-products from cereal grain straws (such as wheat or barley), sugar cane bagasse, sorghum, kenaf, and fiber crops such as bamboos, esparto grass, manila hemp, and flax.

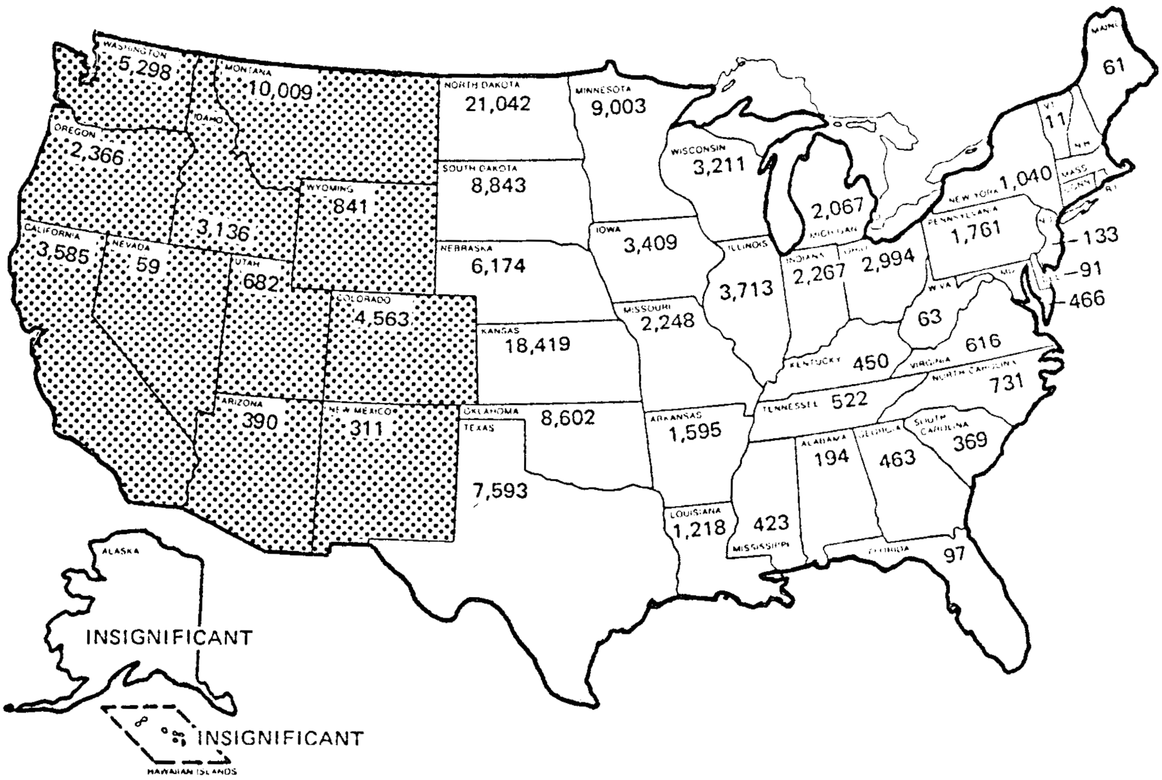
Of the crops presently grown in the western geothermal areas, those crops listed at the end of the ruminant feed section would be prime targets. A state-by-state estimation of cereal straws (wheat, rye, rice, oats, barley) is mapped in Figure 11.2.

The major economic limitation to utilization of these sources is the cost of collecting and transporting the fibers. Since heat and water are requirements for pulping, perhaps it is feasible to build a small pulping plant over a geothermal site where agricultural cellulosic wastes are generated most of the years. Southern California may be worth considering, although Montana produces large quantities of straw (see map).

<u>Herbaceous Waste</u> (IA 2)

Herbaceous waste is the leafy, relatively nonfibrous material that is separated from the seed or tuber portion during harvesting or in preparation for processing. Because it has low fiber content, it can serve as an animal feed for ruminants or a high-grade feed for the higher requirements of poultry or swine. Protein extraction can yield a high-quality food (leaf-protein concentrate) for human consumption.

We can only discuss leafy field waste generically since no systematic study of quantities, crop species, and locations has been done. Table 11.1 classifies the "geothermal crops" into the major classes of waste. Leafy wastes are candidates for dehydration, and turfgrass, cauliflower leaf waste, artichoke trimmings, kenaf tops and pimento waste have been field-tested with dehydration equipment by the USDA's Western Regional Research Laboratory. Generally, these wastes are digestible enough to feed to ruminant or nonruminant livestock without pretreatment. Dehydration can produce a high-quality cured feed and we have shown evidence in this report that low temperatures can accomplish this task without significant nutrient loss.



The geothermal states are shaded.

SOURCE: Dwight L. Miller, 1972, "Energy from Agriculture" in U.S. Energy Outlook: An Interim Report by the New Energy Forms Task Group, National Petroleum Council, p. 71.

Figure 11.2. Quantities and Locations of Cereal Straws in the United States (1000 tons per year).

Table 11.1

DISTRIBUTION OF HERBACEOUS OR LIGNIFIED WASTES AMONG CROPS GROWN NEAR LOW-TEMPERATURE GEOTHERMAL SOURCES*

Crop Growing Near Geothermal Resource	Lignified Waste	Herbaceous Waste	Comments
GRAINS			
Barley	x		Straws are left in the field.
Corn	x		
Oats	x		
Rice	x		
Ryegrass	x		
Sorghum	x		
Wheat	x		
FRUITS			
Apples		x	Undesirable fruits are culled, generating large amounts of wasted fruit. Leafy wastes are left in the field after harvesting cantaloupes.
Apricots		x	
Cantaloupes		x	
Grapes		x	
Oranges		x	
Peaches		x	
Pears		x	
Plums and Prunes		x	
Sweet Cherries		x	
VEGETABLES			
Carrots		x	Unused parts such as tops and vines are often left in the field. Lettuce leaves are removed and left in the field; the inner part may be packed in plastic wrappers before transporting. Peanut shells are lignified waste.
Celery		x	
Dry Beans		x	
Dry Onions		x	
Green Peas		x	
Hot Peppers		x	
Irish Potatoes		x	
Lettuce		x	
Peanuts	x	x	
Snap Beans		x	
Sugar Beets		x	
Sweet Potatoes		x	
Tomatoes		x	
OTHER CROPS			
Alfalfa Hay			→ Very little waste with alfalfa
Cotton	x	x	→ Stalks are like straw—leaves are herbaceous
Flaxseed	x		
Garlic		x	
Hops		x	
Pecans	x		→ Pecan shells are lignified waste
Peppermint		x	
Safflower	x		

*Information helpful in constructing this table was provided by Mr. Peter Chapogas at the U.S. Department of Agriculture.

Leafy wastes can also provide a source of plant protein. Leaf-protein concentrate is the subject of intensive worldwide research because of present and potential large-scale protein shortfalls in developing and developed countries. A comprehensive study of the kinds and quantities of harvest wastes produced worldwide would be helpful in evaluating their potential for protein. No crop is grown specifically for its leaf protein except possibly alfalfa, which is grown mainly as a forage for ruminants. A heat-requiring process for producing alfalfa leaf-protein is discussed in the alfalfa section of this chapter.

Animal By-Product (Manure) (IB)

Animal wastes and especially feedlot wastes (FLW) are a growing concern in the United States and research has been underway to develop ways to dispose or recycle the annual 2 billion tons[9] of wastes in a sanitary and economical manner. Those methods that could use heat are outlined here.

Spreading manure on land as fertilizer has long been practiced, and drying FLW with heat before transportation is an obvious possibility. Processes to convert manure into animal feed may also use heat to dry or to destroy pathogenic organisms, but care must be taken to minimize heat damage to the nitrogen or energy fractions.[10]

FLW consists of two major fractions: a digestible crude protein and a nearly indigestible cell-wall fraction containing cellulose, hemicellulose and lignin. Both converting the cell-wall fraction to a feed and converting it to a construction material can utilize heat. Converting the carbohydrate fraction to a feed can involve incubation of a celluloytic fungus with the fraction in a warm (84°F) environment and feeding the whole fungus-substrate mixture that has become more proteinaceous. "Fungal fermentation appears to be a practical way to reduce bulky indigestible organic matter in FLW and to improve and increase proportionately its protein content."[11] Alternatively, the enzyme can be isolated from the fermentation medium and used in a number of ways, including incubating (122°F) with commercial feed. Data have shown that chicks eating enzyme-treated commercial chick starter grew more quickly than controls.[12]

Converting the indigestible FLW fraction to a construction material (hardboard) involves drying (122°F) and, after combining with a resin, heating to 250-300°C before prepressing. Initial results show that formation of a hardboard from FLW fiber is feasible.[13] Perhaps the geothermal water could be augmented with fuel, so that these high temperatures could be reached.

The problem of animal wastes must be solved as legal and economic constraints bear down on the livestock industry. Research efforts to remedy the problem include processes that require heat in the low-temperature geothermal range.

New Protein Sources: Alfalfa and Other Crops (IIA 1a)

Increasing worldwide population and the disparity of nutritious food between the wealthy and poor nations have been the subject of intense international concern for the past several years. The following is a quote from the preface of the proceedings of a 1968 international symposium on novel protein products:

> The lack of high-quality food proteins in large areas of the world is one of the great challenges of our generation. Apart from being the main cause of the high mortality rate amongst children in developing countries, protein deficiency is known to retard the growth of the child and may impair mental development as well. The precarious and complex protein problem requires determined international action and calls for the cooperation of a large number of scientific disciplines.[14]

The United States is and will continue to be rich in agricultural resources, but research toward developing new protein foods can provide less-fortunate nations with the technology to be well fed as well as generate domestic or exportable products for our own benefit.

A number of crops have been considered as new sources of protein. These include:[15]

(A) Non-endospermous "seeds"--usually achenes

cottonseed	castor seed
sunflower seed	rapeseed
safflower seed	peanuts
sesame seed	linseed

(B) Endospermous "seeds"--usually caryopses

wheat bran	oats
rice bran	coconut
triticale and its bran	

(C) Leafy plants

alfalfa	vegetable wastes
clovers	aquatic plants
grasses	miscellaneous

Of these crops, those that are near geothermal sources, plus other "geothermal crops" that have been identified as good leaf sources[16] give us a target list:

cottonseed	peanuts	oats (bran)	bean (leaf)
safflower seed	wheat (bran)	rice (bran)	potato (leaf)
flaxseed	wheat (leaf)	alfalfa	sugar beet (leaf)

New technologies to extract protein from categories A, B, and C can make use of heat. Category A, including cottonseed, safflower seed, peanuts, and possibly flaxseed, is in the same category as soybeans; and so, with modifications for individual differences, the extraction technology is already developed. The whole seed is conditioned by steaming to

- partially denature the protein to permit easy removal of the oil
- deactivate enzymes
- reduce oil viscosity
- and adjust the moisture content for optimum oil removal.[17]

Category B, including wheat, rice, and oats, involves the use of the outer nonstarchy, high-protein layers of the seeds called "millfeeds." One approach to obtaining cereal protein concentrates from millfeeds discussed by Saunders and Kohler[18] uses heat as an option to recover the protein-lipid concentrate from the rice or wheat extract and possibly heat to dry the concentrate on the oat wet process.

Category C, leafy plants, is potentially the largest source of new protein and includes alfalfa and herbaceous by-products such as bean, potato, and sugar beet leaves. Alfalfa leaf-protein is the subject of intense world-wide research and is the top candidate for commercialization of leaf-protein concentrate. We have focused on current developments in the United States and find that heat is a necessary input in some of the new extraction methods.

While alfalfa contains relatively low amounts of energy and has limited palatability, it provides a large amount of protein--even more than soybeans, as shown by the data in Table 11.2. Since most of the protein and vitamins are located in the leaves while most of the fiber is in the stem, separation or fractionation of these two plant parts can improve and better adapt alfalfa to current and future markets.[19] The "separation milling" process can generate these fractions by sieves or air separation, and such separated products have been produced commercially.[20]

<u>The wet-separation method of leaf-protein extraction</u>. The wet-separation process involves crushing, which parts the fiber-rich residue from the protein-rich juice. This process separates the two feed fractions and also provides a method of producing leaf protein for human consumption. Compared to dehydrating chopped alfalfa in dryers, crushing or pressing dewaters the alfalfa significantly without the use of expensive natural gas, enhances the digestibility and palatability for non-ruminants,[21] and provides a greater adaptability to the market. Table 11.3 shows the percentage reduction in gas needs with various degrees of pressing. It also has been demonstrated that subsequent drying of the residue (presscake), as performed in conventional dryers, allows a greater dehydration rate than with conventional greenchop dehydration because the crushed cells yield water much more readily than intact ones.[22] This also would reduce the energy needed.

Energy savings: It is useful to compare the theoretical energy used in the wet-pressing method with that of conventional dehydration of greenchop. The answer is not obvious: while wet-pressing plus drum dehydration of the

Table 11.2

PROTEIN PRODUCTION BY PLANTS AND ANIMALS (KG/ACRE)

Alfalfa*	675
Soybeans	260
Barley	195
Milk (from forage)	144
Broiler hens (from grains)	66
Beef (from forage)	49
Pigs (from grains)	46

*Value is true protein.

SOURCE: W. J. Bray, "Green-Crop Fractionation," New Scientist, Vol. 70, No. 995, April 8, 1976, p. 66.

Table 11.3

FUEL SAVINGS BY WET PROCESSING*

	Wet product to dehydrator (lb)	Moisture in cake (%)	Water to evaporate in dehydrator (lb)	Water to evaporate from protein (lb)**	Water to evaporate from brown juice, serum (lb)***	Total gas required for evaporation (cubic feet)	Reduction in gas needs (%)****
Unpressed lucerne	100	80	79	-	-	118	-
Presscake, 35% press	65	75	47	4.5	29	89	25
Presscake, 50% press	50	70	34	6.5	41	81	31
Presscake, 62.5% press	37.5	63	23	8.2	52	71	41

*Calculations based on processing 100 lb. fresh alfalfa containing 20 lb. dry matter.

**Atmospheric-pressure dryer taking product to 93% dry matter (DM) using 1.5 cubic feet of gas per pound of water evaporated.

***Triple-effect evaporator taking product to 50% DM syrup using 0.42 lb. steam per pound of water evaporated.

****This is a reevaluation. (See text)

SOURCE: G. O. Kohler, E. M. Bickoff, and D. DeFremery, "Mechanical Dewatering of Forage and Protein Byproduct Recovery," First International Green-Crop Drying Congress, Oxford, England, 1973.

presscake requires two steps, the presscake dehydration involves less water, and this water is easier to remove after the cells have been crushed.[23] One comparison of these two systems shows a 25 percent reduction in natural gas required with the wet-pressing system.[24] However, this comparison does not include the energy required to generate the steam used in coagulating the protein-rich curds from the whole juice or the steam used in pelleting the presscake. In research performed by Vosloh et al., the energy used in steam coagulation and curd drying are roughly equivalent; pelleting steam uses about 1 to 2 percent of the total.[25] Using these relationships together with the evaluation by Kohler and others, we show a reduction of 17 percent using the wet-processing system described in the literature.[26] Improvements in this process are presently being engineered by the U.S. Western Regional Research Laboratory, and so even better results will be forthcoming.

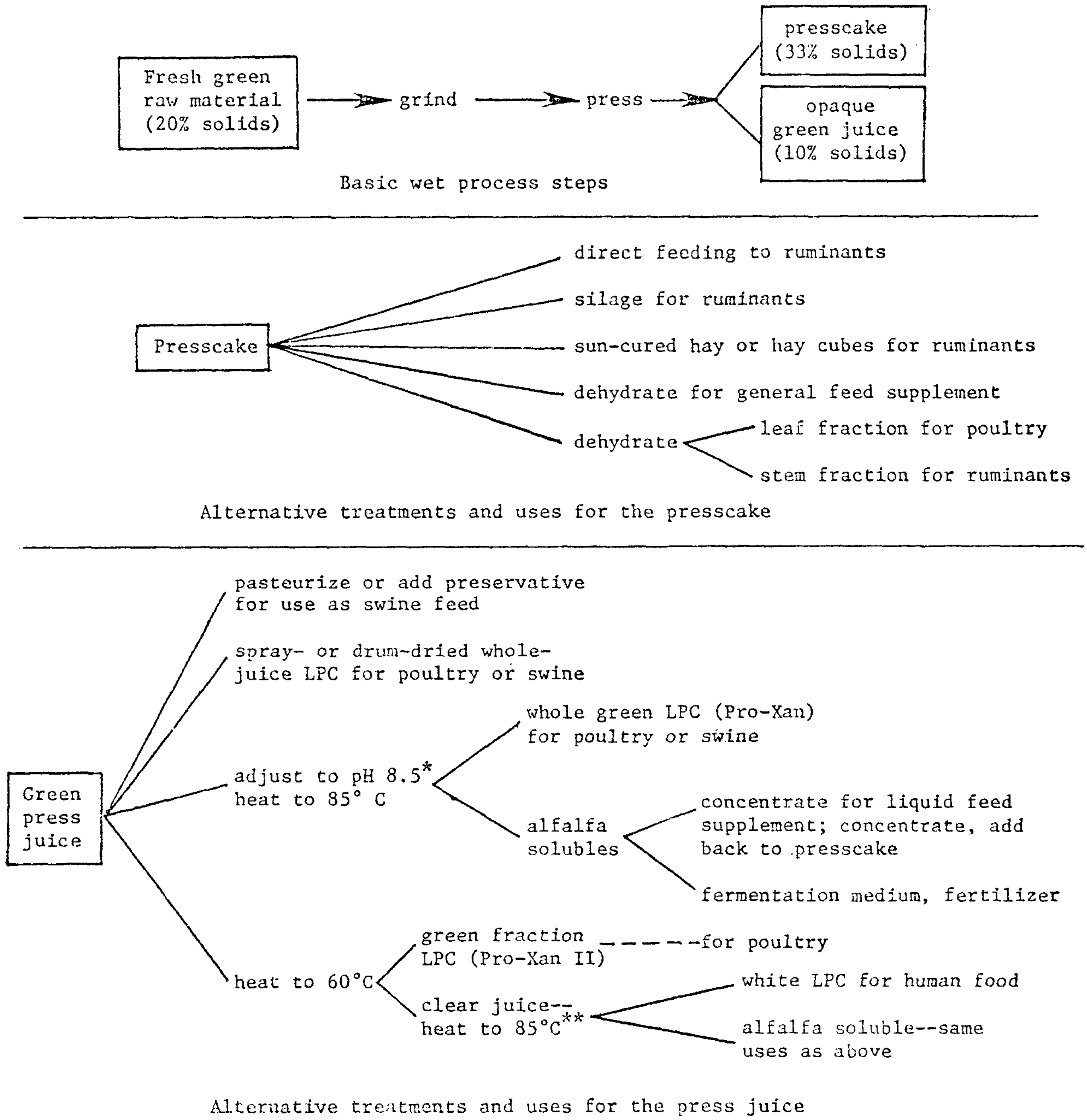
The Pro-Xan research: Because of the potential improvement in quality, new markets, and energy savings, wet processing (or mechanical dewatering) of alfalfa has been and is currently a promising research area. Much of the research in the United States centers around the production of the high-protein and high-xanthophyll coagulant from the juice fraction, which is termed "Pro-Xan." 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.[27] Figure 11.3 illustrates the many variations of the wet-fractionation procedure and the places where heat is needed.

Apparently commercialization has been held back because of the lack of a developed market and uncertainty surrounding technical optimization. A new economic assessment, including some technical improvements, is forthcoming from the Western Regional Research Laboratory in Albany, California. Dr. George Kohler, a project director at the laboratory, reports that more interest in commercialization is emerging in the United States. Even more enthusiasm is found in Europe and especially in France, where a commercial plant has been in operation for a number of years. Leaf-protein research has been more intensive in Europe because soybeans do not grow well in the European climate.

Because the presscake has been partially dewatered enabling a reduction in the temperature requirements for complete dehydration, and because the juice fraction undergoes heat processes of relatively low magnitude, low-temperature geothermal water might make a sensible energy source for the wet-fractionation procedure.

Grains, Fruits and Vegetables (IIA 1b)

We have considered the processing of all crops near geothermal sources as potential markets for heat and have constructed a chart (Table 11.4) which connects the commodity with the process.



SOURCE: George O. Kohler, "Wet Processing of Alfalfa," Twelfth Technical Alfalfa Conference Proceedings, American Dehydraters Association, Mission, Kansas, 1975, pp. 66, 67.

*The methods of coagulating the whole LPC include acidification and precipitation with solvents.

**The methods of recovering white LPC at this stage include acidification, ultrafiltration, and gel filtration.

Figure 11.3. Wet Processing of Alfalfa

Table 11.4

CONVENTIONAL HEAT-REQUIRING PROCESSES
FOR THE GEOTHERMAL CROPS

Crop Growing Near Geothermal Resource	Heat Requiring Process*	
GRAINS		
Barley	drying brewers' malt (160°-180°F); drying distillers' malt (120°-140°F); bin drying (110°F max.)	
Corn	wetmilling, steeping (125°F); drying (140°F max.); starch drying	
Oats	drying; cooking oat flour	
Rice	drying (130°F max.); parboiling; quick-cooking process	
Ryegrass	mainly a feedstuff	
Sorghum	drying (140°F max.); mainly a feedstuff	
Wheat	baking	
FRUITS		
Apples	drying (165°F max. tunnel, 135°F max. kiln); applesauce (steam cooked); canned slices (steamed); pasteurized bottled juice	
Apricots	drying (150°F max.)	
Cantaloupes	consumed fresh	
Grapes	drying; processing to wine, canned, frozen (140°-150°F) products	
Oranges	peel softening; packing sections; pasteurizing canned juice (195°F); sterilizing chilled juice (240°F)	
Peaches	drying (155°F max.); peel scalding	
Pears	drying (155°F max.)	
Plums and Prunes	drying (165°F max.); leaching for juice	
Sweet Cherries	syruping (120°-140°F); exhausting air in canning (212°F)	
VEGETABLES		
Carrots	drying (160°F max.)	Blanching in hot water or live steam is required for most vegetables. There is much variation among canners in the temperatures and equipment used in blanching, for example, blanching in hot water at 170°-212°F or in live steam.**
Celery	drying (180°F max.)	
Dry Beans		
Dry Onions	drying (160°F max.)	
Green Peas		
Hot Peppers	drying (150°F max.)	
Irish Potatoes	drying (275°F max.)	
Lettuce	consumed fresh	
Peanuts	blanching and roasting	
Snap Beans		
Sugar Beets		
Sweet Potatoes	healing (85°F max.)	
Tomatoes	drying (195°F max.)	
OTHER CROPS		
Alfalfa Hay	protein extraction (140°-185°F)	Potential protein-concentrate source
Safflower	oil is steam-distilled	
Cotton	lint and seed drying (220°F max.)	
Flaxseed	seed drying (150°-175°F max.)	
Garlic	drying (180°F max.)	
Hops		
Pecans		
Peppermint		

*Information presented here has been compiled from data supplied by Midwest Research Institute and from process descriptions found in Arnold H. Johnson and Martin S. Peterson (eds.), Encyclopedia of Food Technology (Westport, Conn.: The AVI Publishing Co., Inc., 1974).

**Georg A. Borgstrom and Jerry F. Proctor, "Nutrition: Food Composition and Nutrient Aspects of Food Processing" in Johnson and Peterson (eds.), Encyclopedia of Food Technology, p. 640.

In order to obtain a first look at the proximity of food-processing facilities to the geothermal sources, we counted the number of food-processing plants that appear in counties containing identified geothermal resources. The results are shown in Table 11.5. California, Washington, Oregon, and Idaho have the most food-processing activity as well as the most activity within the source counties. Thus, geothermal heat might be useful in food-processing in the Western United States.

Animal Products (IIA 2)

Some processes for animal products require heat and these are identified in Table 11.6.

Process-Waste Utilization (IIB)

In addition to potential geothermal applications to agricultural processes themselves, the solutions to disposing of process wastes may also offer potential applications. Because the most economical method for solving the waste problem may not be simply a new end-of-pipe treatment but may involve modifying the entire food-processing system, we must be cautious in suggesting heat applications as a means for meeting EPA guidelines. With this caveat in mind, we surveyed recent literature for possible methods of treating food processing wastes; those for which geothermal heat appears to be applicable are outlined in Table 11.7.

* * * * * *

The preceding information suggests at least two functional combinations or synergisms. These are described below.

Beef and Paper Plant (Grain Production/Harvest Waste/Feedlot Manure Processing)

Grains grown specifically for feed can be harvested and the straws processed in a heat-requiring paper and paperboard plant. The grain could supply a large system of feedlots where manure could be collected and heat-processed.

The paperboard plant could use the cellulosic fraction of the manure in a heat-requiring hardboard process. The protein fraction of the manure could be added to the feed grain directly or spread on the land for fertilizer. Since a large lumber industry already prevails in the Northwest, this synergism might best be initially assessed for the southwestern states.

Table 11.5

NUMBER AND GEOTHERMAL SOURCE PROXIMITY
OF THE CANNING, FREEZING AND PRESERVING PLANTS
WITHIN THE GEOTHERMAL STATES

GEOTHERMAL STATES	TOTAL NUMBER OF PLANTS IN THE STATE	NUMBER OF PLANTS IN A SOURCE COUNTY*
California	242	44
Washington	113	26
Oregon	74	24
Idaho	28	10
Arizona	9	6
Utah	5	2
Montana	3	1
Nevada	1	1
New Mexico	1	1
Colorado	12	0
Wyoming	0	0

*A "source county" is a county containing one or more U.S.G.S.-identified geothermal sources.

SOURCE: The Directory of the Canning, Freezing, Preserving Industries 1976-1977 (Westminster, Maryland: Edward E. Judge & Sons, Inc., 1976).

Table 11.6

HEAT-REQUIRING ANIMAL PRODUCTS AND PROCESSES

Animal Product		Process Description
DAIRY PRODUCTS*	Filtration:	Usually milk is heated to about 90-110°F before filtration.
	Pasteurization:	The maximum temperature is 166°F; lower temperature may be used for longer periods.
	Ultra-High Temperature Pasteurization:	Temperatures of 270-300°F are alternatively used for milk, but this process has found application also in the making of ice cream mix, cream, and cream toppings.
	Vacuum Pasteurization:	Using temperatures from 194-200°F, V. P. is an efficient method to remove feed and weed flavors from cream for butter making.
	Milk Sterilization:	Live steam can be used to heat milk to 300°F. Sterilized milk is used in places where refrigeration is not generally available (armed forces, etc.).
	Aseptic Canning:	Superheated steam is used at atmospheric pressure (550°F maximum). The cans themselves reach temperatures of 425°F. Aseptic canning is used for whole milk, concentrated milk, chocolate milk, coffee cream, whipping cream, ice cream mix, and formulated infant foods.
	Dried Milk:	20 percent of the U.S. crop requires a 160°F temperature to spray dry milk.
EGGS**		Egg products, such as albumen, plain yolk, sugar yolk and whole egg blends require heat for pasteurization (130-145°F). Over 11 percent of the U.S. egg crop is processed;
MEAT***	Beef:	75 percent of all beef is consumed fresh. The remainder is processed into bologna, frankfurters, sausage and other meat composites, which are sold pre-cooked.
	Pork:	Pork is sold pre-cooked as hams. Federal regulations require the internal temperature of the ham to be 137°F or higher to qualify for the pre-cooked designation.
	Poultry:	90 percent of the fowl, broiler and small turkey fryers are processed through broiler-processing type plants, that use hot water to scald the birds prior to defeathering. Scald water is around 127-130°F. Much effort is currently centered around replacing this scalding process with some technique which will accomplish the same feather-loosening effect withoug scalding the birds in unsanitary water. Processes in use or under development could make use of geothermal steam: a spray and steam scalder, a combined hot-water spray with picking action, and subatmospheric steam-scalding.
HONEY****		Honey is heated to facilitate blending, destroying yeasts (140°F), pasteurization (170°F) and crystallization (80°F).

*Lincoln M. Lampert, Modern Dairy Products, (New York: Chemical Publishing Co., Inc., 1970).

**Arnold H. Johnson and Martin S. Peterson (eds.), Encyclopedia of Food Technology, (Westport, Conn.: The AVI Publishing Co., Inc., 1974).

***For beef and pork data: Ibid. For poultry data: George E. Inglett (ed.), Symposium: Processing Agricultural and Municipal Wastes, (Westport, Conn.: The AVI Publishing Co., Inc., 1973).

****Arnold H. Johnson and Martin S. Peterson, op. cit.

Table 11.7

HEAT-REQUIRING PROCESS WASTE TREATMENT OPPORTUNITIES

Kind of Industry	Waste Treatment Process
Poultry Slaughtering*	Feathers, feet, heads and viscera may be heat processed into meal for feed. In all processes, the product is at least heated sufficiently to destroy any microorganisms (at least 212°F), but various individual methods are currently used.
Egg Processing**	Broken eggs make an important contribution to the egg-processing waste steam. Eleven percent of eggs produced in the United States go to egg-breaking plants for processing. Processing this waste reduces the BOD of the plant and would provide a high-protein material for use in animal feeds. In a recent study on the egg-breaking industry performed by the EPA, three methods for converting this waste were suggested and all required heat.
Fruit and Vegetable Processing	Peeling and blanching of fruits and vegetables generates large quantities of waste material that can no longer be discarded indiscriminately. Waste disposal must now become part of the cost of doing business. If a cheap heat source were available, solid wastes and sludges could be dried for animal feed or fertilizer. Drying would not only cure the waste problem, but lessen the weight to facilitate transportation.

*D. Hamm, R. E. Childs and A. J. Mercuri, "Management and Utilization of Poultry Processing Wastes," in George E. Inglett (ed.), Symposium: Processing Agricultural and Municipal Wastes (Westport, Conn.: The AVI Publishing Co., Inc., 1973).

**W. J. Jewell, et al., Egg Breaking and Processing Waste Control and Treatment, U.S. Environmental Protection Agency (EPA-660/2-75-019) (Washington, D.C.: U.S. Government Printing Office, June 1975).

Chicken and Egg Farm (Alfalfa Feed/Chicken Slaughtering/Egg Processing)

Alfalfa can be dehydrated with a belt dryer, or wet-processed to produce Pro-Xan. Both products are useful ingredients in chicken feed. The Pro-Xan process produces mainly fibrous presscake of somewhat lower protein value, but this can be fractionated and pelleted for use as a chicken feed ingredient with the stem fraction sold as cattle feed.

Chicken-slaughtering plants use large quantities of hot water for the feather-loosening scalding step. In addition, wastes from these plants can be heat-processed into a meal for feed.

The egg-breaking plants use heat in pasteurizing the eggs themselves and could potentially heat waste from the washing step to generate protein-rich feed.

Obviously, a chicken and egg farm would benefit by integrating the final product systems with the feed-producing system. California has a well-developed poultry industry and would appear to be the natural place to test this idea.

REFERENCES

1. Terry Klopfenstein and Walter Koers, "Agricultural Cellulosic Wastes for Feed," in George E. Inglett (ed.), Symposium: Processing Agricultural and Municipal Wastes (Westport, Conn.: AVI Publishing Co., Inc., 1973), p. 39.

2. Ibid., p. 39.

3. A quick calculation shows about 4-1/2 atmospheres (or approximately 4 kg/cm^2) is the upper limit of pressure generated by 300°F water.

4. Manure processing for recycling to feeds provides a number of opportunities for heat, and lower temperatures are desired in order to prevent nitrogen losses. Heating not only renders greater digestibility, but dehydrates and kills pathogenic microorganisms. [See L. W. Smith, "Nutritive Evaluations of Animal Manures," Agricultural and Municipal Wastes (Westport, Conn.: AVI Publishing Co., Inc., 1973), p. 69.]

5. George O. Kohler, "Animal Feeds from Vegetable Wastes," in Proceedings, First National Symposium on Food Processing Wastes, April 6-8, 1970, U.S. Department of the Interior, Federal Water Quality Administration, 1970 (Washington, D.C.: U.S. Government Printing Office), p. 385.

6. Ibid., p. 386.

7. Dwight L. Miller, "Paper and Paperboard from Cellulosic By-Products," Symposium: Processing and Municipal Wastes, p. 122.

8. Ibid., p. 119.

9. J. H. Sloneker et al., "Processing Animal Wastes for Feed and Industrial Products," in George E. Englett, (ed.), Symposium: Processing Agricultural and Municipal Wastes (Westport, Conn.: The AVI Publishing Co., Inc., 1973), p. 13.

10. Smith, "Nutritive Evaluations of Animal Manures," p. 69.

11. Sloneker et al., "Processing Animal Wastes ...," p. 24.

12. Ibid., p. 26

13. Ibid., p. 20.

14. A. E. Bender et al., (ed.), Evaluation of Novel Protein Products, Proceedings of the International Biological Programme (IBP) and Wenner-Gren Center Symposium (Stockholm, 1968) (New York: Pergamon Press, 1970), p. IX.

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15. G. O. Kohler and C. K. Lyon, "The Processing of Unconventional Protein Sources," preprint (July 26, 1976).

16. N. W. Pirie, "Leaf Protein" in N. W. Pirie (ed.), Food Protein Sources (Cambridge: Cambridge University Press, 1975), p. 135.

17. Kohler and Lyon, "The Processing of ...."

18. R. M. Saunders and G. O. Kohler, "Concentrates by Wet and Dry Processing of Cereals," in N. W. Pirie (ed.), Food Protein Sources (Cambridge: Cambridge University Press, 1975), p. 135.

19. On a nationwide or worldwide scale, alfalfa supplies feed constituents to two categories of livestock. These are ruminant animals (such as cattle, sheep, or horses) that need long-fiber "roughage" for the best performance, and nonruminants (such as chickens or swine) that have a limit to their alfalfa consumption because of the presence of significant quantities of indigestible fiber.

20. G. O. Kohler, E. M. Bickoff, and W. M. Beeson, "Processed Products for Feed and Food Industries," in C. H. Hanson (ed.), Alfalfa Science and Technology (Madison, WI: American Society of Agronomy, Inc., 1972), p. 664.

21. P. R. Cheeke, "Progress in Development of Alfalfa as a Feedstuff for Non-Ruminants," Feedstuffs, Vol. 49, No. 9 (February 28, 1977), p. 50.

22. G. O. Kohler, E. M. Bickoff, and D. DeFremery, "Mechanical Dewatering of Forage and Protein Byproduct Recovery," First International Green-crop Drying Congress, Oxford, England, 1973.

23. Ibid.

24. Ibid., (25 percent reduction with the green-chop pressed to 65 percent of original weight).

25. C. J. Vosloh, Jr., et al., Leaf Protein Concentrate (PRO-XAN) from Alfalfa: An Economic Evaluation, National Economic Analysis Division, Economic Research Service, USDA, Agricultural Economic Report No. 346; private communication with C. J. Vosloh.

26. This was done by assuming that 4.5 percent of the total drying, coagulating, pelleting energy is used by coagulation and 1.5 percent is used by pelleting. Since coagulation energy and curd-drying energy are equivalent, and since pelleting represents a value approximately one third that of the coagulation, we were able to use the energy for curd dehydration in the Kohler study as an index and add this to the numbers reported in that study.

Energy needed to dry curds = 6.75 cubic feet natural gas
Therefore, energy needed to coagulate = 6.75 cubic feet natural gas
And 6.75 x 0.33 needed to pelletize = 2.22 cubic feet natural gas

Thus approximately 9 cubic feet is added, making the reduction 17 percent, not 25 percent. (Although in Vosloh's study the brown juice was not dried separately, it was added back to the presscake prior to drying, making the two cases roughly the same.)

D. deFremery, et al., "Composition and Uses of Pro-Xan and Pressed Residue," Twelfth Technical Alfalfa Conference Proceedings (Mission, KS: American Dehydrators Association, 1975), p. 75.

CHAPTER 12: POLICY ANALYSIS

Introduction

To review: we have identified the general areas of coincidence between geothermal resources, alfalfa, and other agricultural products. We have studied the thermodynamics of the removal of moisture during the drying process. We have analyzed the drying process, both from the standpoint of dryer design and economics. We have examined the infrastructure of the alfalfa drying industry. We have examined the possibility of drying several agricultural products at drying centers and the possibility of using geothermal heat as an energy source in certain other agricultural and food applications. Now the question remains: what government action, if any, should be taken to encourage the use of hydrothermal resources in applications such as those studied here?

We assume that there are two basic objectives that the government might pursue through the introduction of hydrothermal resources in the drying or processing of agricultural products. These are

- decreasing the amount of natural gas consumed
- utilizing an energy resource which is largely unused

Both of these goals seem quite appropriate. We estimate that 64×10^{12} Btu's per year are consumed in the form of fossil fuel in the drying and processing of agricultural products in the twelve crop categories studied. Table 12.1 presents the utilization of fossil fuel by crop and by various operations in a selected year.

The second goal, utilizing hydrothermal resources, also seems appropriate and important. While the extent of our geothermal resources is currently unknown, clearly a vast amount of energy is involved. Our study centered around the use of resources ranging in temperature from about 90°C to 150°C; various authorities have estimated the total amount of energy contained in resources within this temperature range; USGS, for example, estimates that these resources contain 137×10^{16} Btu's (D. F. White and D. L. Williams (Ed.), Assessment of Geothermal Resources of the U.S.--1975; Geological Survey Circular 726). For comparison, this is equivalent to 134×10^{15} standard cubic feet of natural gas or 236×10^{9} barrels of oil.

Stated most simply, how can the geothermal resources in the temperature range of 90°C to 150°C be used to substitute for natural gas consumed in agricultural drying processes? In general there are two approaches which could be used to effect this substitution; these are

- modifying existing drying systems so that they can utilize geothermal resources rather than natural gas as an energy source

Table 12.1

SUMMARY OF ENERGY USE BY DEHYDRATING INDUSTRIES
WITHIN 50 MILES OF GEOTHERMAL RESOURCES
AND IN WHOLE UNITED STATES

Drying Industry	Description and Location	Estimated Annual Drying Energy Consumed, 1976		
		Total U.S.	≤50 miles from GT	
		10^9 Btu's	10^9 Btu's	% U.S.
Sugar beet pulp dehydration	Dried byproduct of beet sugar production used as feed ingredient; AZ, CA, CO, ID, MT, OR, UT, WA, WY; KS, MI, MN, NB, ND, OH, TX.	32,000	9,700	30%
Alfalfa dehydration	Artificially dried alfalfa hay sold as feed ingredient. Main concentration is in KS, NB; geothermal states: AZ, CA, CO, ID, MN; 15 other states.	15,000	1,400	9%
Potato dehydration	Dehydrated granules, flakes, slice, dice and starch plants included; potato chip and frozen products excluded. CO, ID (concentration), NV, OR, WA, WY; also MN, NY, MI, ND, MN.	7,300	4,700	64%
Cotton ginning	Heat usually required to reduce moisture of raw cotton; AZ, CA (large), NV, NM; also TX (large), 12 other states.	3,500	490	14%
Onion dehydration	Sliced, chopped, minced, granulated and powdered, dried onion is mostly an input to other processed foods like catsup and chili sauce; CA only.	1,500	1,000	67%
Prune dehydration	Nearly all prunes are artificially dried, mostly in CA, small amounts in OR, WA.	1,300	1,200	92%
Rice drying	Drying is required before milling; CA produces a large amount of rice; TX, LA AR, are large producers, some in MS and MO.	1,300	250	19%
Apple dehydration	Sliced or diced artificially dehydrated apples; CA and WA are the large producers; NY produces smaller amount.	630	340	54%
Chili and other vegetable dehydration	Chili is largest component, but carrots tomato powder, bell peppers and at least 15 others dried in small amounts; CA, NM (large), WA; also LA, NC (sweet potatoes).	400	310	78%

Table 12.1 (Cont.)

Drying Industry	Description and Location	Estimated Annual Drying Energy Consumed, 1976		
		Total U.S.	≤50 miles from GT	
		10^9 Btu's	10^9 Btu's	% U.S.
Garlic dehydration	Mostly sold as powder or granules, dried garlic is retailed and used in canned dog food and other prepared foods; CA only	300	250	83%
Raisin dehydration	Some grapes are dried artificially as the "golden bleached" variety; CA only.	300	100	33%
Peach, pear, apricot dehydration	Some prune, raisin and apple dehydrators produce small amounts, but mostly sun-dried; CA, WA.	17	9	53%
Total	12 drying industries	64,000	20,000	31%

- introducing totally new drying systems which utilize geothermal resources as an energy source

In this chapter we analyze both of these approaches from the government's standpoint to determine the cost and benefits which might be achieved by either. In addition, certain alternatives to the substitution of geothermal energy are analyzed for the alfalfa case (e.g., field wilting, followed by conventional drying; and sun curing). These alternatives are included because they were seen as possible means of achieving the same or better results than drying with geothermal fluids, but at potentially lower cost.

Definition of Cases

To conduct the policy analysis, a number of alternative cases were studied. Each case involved three elements: a strategic approach, a drying configuration, and a crop application. These cases are presented in Table 12.2. This figure illustrates the study's concentration on alfalfa; both modification to existing dryers and new drying systems are included. Simple modifications to existing dryers are considered for crops other than alfalfa: means of predrying are considered; the use of new drying systems is considered for combinations of crops in, for example, multicrop drying centers; and alternatives to energy-intensive drying are also considered.

Evaluation Criteria

Each of the various cases was analyzed in turn to determine the consequences to the nation of implementing such approaches. The analysis involved determining several parameters which could serve as the basis for judging the relative effectiveness of each of the approaches. These parameters were as follows:

- Amount of natural gas saved
- Marginal product cost
- Total investment required
- Industry impact
- Impact on nutrition
- Timing

The evaluation parameters and other considerations are presented below for each of the cases.

Case 1. Existing system modification; heat exchanger; alfalfa. This is the simplest and least ambitious of all approaches considered. Basically, geothermal resources are used to provide a "preheat" to the air entering a conventional rotary dryer used in dehydrating alfalfa. (This case is physically identical to Case 1 of Chapter 6.)

Table 12.2

CASES INCLUDED IN POLICY ANALYSIS

Case	Strategic Approach	Dryer Configuration	Crop Application
1	Existing system modifications	Heat exchanger predry	Alfalfa
2	Existing system modifications	Heat exchanger predry	Other single crop
3	Existing system modifications	Steam-tube rotary-drum predry	Alfalfa
4	Existing system modifications	Press out water to predry; conventional drying	Alfalfa
5	Existing system modifications	Field wilt, to predry; conventional drying	Alfalfa
6	New drying systems	Conveyor dryer	Alfalfa
7	New drying systems	Various dryers	Crop combinations
8	Management strategy	Market substitution	Alfalfa

We have made extreme assumptions about the application of predrying heat exchangers to existing dehy installations. We have assumed that the economics of the Heber case presented in detail in Chapter 9 apply throughout the western United States. We assume that all alfalfa-drying installations that are currently located in the eleven western geothermal states within 50 miles of a geothermal resource could be converted to the use of geothermal energy for preheat using heat exchangers in the existing dryers. To apply the Heber economics to all such cases is grossly unrealistic, but nevertheless represents an upper bound to this strategy. These assumptions are unrealistic because in most instances the existing dryers are too far from geothermal resources; to move the dryers to geothermal resources would impose a transportation cost to the alfalfa dryer, and the market infrastructure, pointed out in Chapter 3, is not able to easily withstand requirements for additional invested capital. Nevertheless this boundary case is interesting because it shows how much natural gas might be saved through the simplest possible modification to existing dryers.

A total of seven plants are included in this analysis. These plants are assumed to produce about 140,000 tons of dehy annually. The peak capacity is taken as 6.8 tons/hour at each plant. This gives a capacity utilization of 35 percent compared to a national average of 33 percent. Assuming 11.5 percent of the dehydration energy can be supplied from geothermal resources (see Chapter 6) this represents an average use of 2.4×10^{10} Btu's/year at each plant.

The parametric economic analysis of Chapter 5 yields an annual operating cost of $450,000 for this set of conditions. This includes amortization of the capital investment as well as maintenance costs and is for the case where only minimal pipeline is required. The cost of geothermal energy for the case then is $19/million Btu's for a net increase of $17/million Btu's over natural gas (taken as $2). The addition of a five-mile pipeline adds approximately $2 to this figure. The total potential gas savings is 1.7×10^8 SCF.

If the additional costs were passed on by the dehydrators to their customers, the price of the product which they produced would have to increase by approximately 20 percent. However, from our analysis, this product would be essentially the same, nutritionally, as a product dried by more conventional means. The conversion, if pursued, could be accomplished in less than 10 years.

On balance, this approach seems quite unrealistic. The industry is not in shape to provide the required capital and, if the government were to provide it, the return in terms of natural gas saved is quite marginal.

Case 2. Existing system modifications; heat exchanger predry; other single crop. This case is quite similar to Case 1 except that the drying of a crop other than alfalfa is considered. More specifically, the drying of Irish potatoes is considered as the focus; this crop was chosen because the estimated value for this crop is second only to alfalfa hay in areas equal to or less than 50 miles from identified hydrothermal resource systems. The value of this crop within the proximity of geothermal resources is about

$170 million per year. In terms of acreage, 368,000 acres of Irish potatoes are located within 50 miles of geothermal resources in the West. Most potato drying occurs in Idaho, Washington, Nevada, and Oregon--all states richly endowed with geothermal resources. In all, some 16 potato drying plants are located within 50 miles of geothermal resources. On the average, each plant uses 2.6×10^{11} Btu's per year. Assuming a nominal operational cycle of 24 hours a day for 280 days per year, each plant utilizes 40×10^{6} Btu's per hour during the drying process. This is a capacity utilization of 80 percent. Each average plant yields about 25 million pounds of dehydrated potatoes per year.

As in Case 1, we assume that the drying plants can be located fairly close to the geothermal resources. The high-capacity utilization by the potato-dehydration industry, and the lower temperatures involved, allow both utilization factor and the economics of scale to reduce the energy costs. The annual operating costs from Chapter 5 for this case are $530,000/plant with minimal pipeline. This yields $2.04/million Btu's as a cost of geothermal energy and essentially no impact on product cost. The potato-drying case differs from the alfalfa drying in that geothermal energy can provide the total amount of heat required for the drying process since the peak drying temperature for potatoes in existing dryers is only 275°F. If this conversion were made for all 16 plants approximately 4.2×10^{12} Btu's per year or 4.2×10^{9} standard cubic feet would be saved.

Thus, to effect a complete conversion to geothermal energy under a set of optimistic assumptions would require an investment of approximately $16 million. For this investment some 4.2×10^{9} standard cubic feet per year would be saved. This amount is quite appreciable. If the dehydrators were required to invest the capital to make this conversion, they would have to add very little to the price of their product in order to recoup this investment. Because the market for dehydrated potatoes is growing, the industry appears to be in fairly good economic condition. Nutritional value of the product would not be affected at all. Timing, as in the earlier case, would range between 5 and 10 years.

Case 3: Existing system modifications; steam-tube rotary-drum predry; alfalfa. In this instance we assume that the alfalfa dryers utilize steam-tube rotary predryers. This policy case is identical to the design Case 5 presented in Chapter 6. As in our earlier discussion we have assumed a limiting set of circumstances to investigate the maximum amount of savings of natural gas which could be realized: all alfalfa dryers in the western geothermal states are converted to steam-tube rotary predryers.

The number of dehy plants, capacity utilization, and total production for this case are taken as those used in Case 1. The differences are the increased capital investment, maintenance costs, and geothermal energy utilization associated with the steam-tube predryer. Using 33 percent of the energy requirement as geothermal (see Chapter 6) a combination of the data in Chapters 5 and 6 yields an increased annual operation cost of $492,000 per plant. This yields a cost of \$7.40/million Btu's for the geothermal energy, or an increase of \$18 for a ton of dehydrated alfalfa. The impact on product cost is similar to Case 1 but the savings in natural gas is approximately three times as large.

As in Case 1, it seems unlikely that the nature of the dehy industry could tolerate such a price increase. The decrease in natural gas utilization, 4.7×10^8 SCF, is more attractive but still costly. Timing for this case could be 5 to 10 years and the impact on nutrition is expected to be minimal.

Case 4: Existing system modifications; press out water to predry; alfalfa. The principal reason for pressing alfalfa before the drying process is to squeeze water out so that less water has to be removed during the drying process. Of course the water which is pressed out of the alfalfa may have some value in itself since it does contain some of the nutrients of the alfalfa. Pressing fresh wet alfalfa will yield a dewatered or "mechanically wilted" residue (presscake) and a protein- and vitamin-rich juice. If the aim in pressing is solely to facilitate the drying of the cellular mass, the juice represents lost nutrient value.

Nevertheless, in the system we envision the alfalfa would be brought to the dehydration site, mechanical rollers would press out some of the liquid content, and then the partially dried alfalfa would be sent through conventional dehydrators. Geothermal energy is not involved in this process.

We assume that all of the sites in the western part of the United States are converted to this process. We assume that in these seven plants, the process permits the removal of enough water to drop the moisture content of the alfalfa from an initial value of 75 percent to 60 percent. According to the estimates presented in Chapter 7, this would reduce the energy requirements to dry by almost 50 percent. In the aggregate, this would amount to a savings of 6×10^8 standard cubic feet of natural gas.

Of course, it is possible to consider this approach for the nation as a whole since it is not tied to the geography of geothermal resources. In this instance the amount of natural gas which could be saved is 6×10^9 SCF of natural gas.

Assuming for a moment that the pressing mills represent a capital investment of about one-half million dollars each, that the amortization is over a 10-year period, and that incremental operating costs are very small:

- Total investment cost converting the alfalfa dryers in the west amounts to 12 1/2 million dollars.

- Total investment costs converting all dryers in the country amounts to \$125 million.

- The cost of the delivered product is essentially unchanged since the amount of gas saved essentially equals the amortized expenditures for the drying presses.

This approach could possibly be absorbed by the industry without undue impact. The government would probably have to establish a loan program or some kind of subsidy which would encourage the dehydrators to purchase the presses. This activity could be well justified in the minds of the dehydrators on the basis of lowering their requirements of natural gas and thus improving their ability to withstand curtailment. The nutritional impact is, of course, of concern. However, the fluids removed from the alfalfa during the mechanical pressing might be the basis for additional protein-rich products. Research should be performed into the potential uses of such fluids. In addition, the subsequent drying process might be accomplished at lower temperature thus limiting the amount of nutritional destruction which occurs after pressing; thus the net nutritional product may well be unimpaired.

This system could be placed into operation in 3 to 5 years. One interesting impact which should be considered is the fact that presses of the sort which would be required here are currently produced in Sweden, and not in the United States. Therefore, the market for presses that would be created by this policy would have impact on the international balance of payments and, with appropriate incentives, the domestic mill industry.

<u>Case 5: Existing system modifications; field wilt to predry--conventional drying; alfalfa</u>. In this case the alfalfa is permitted to field wilt before being taken to the dehydrator for final drying. The field-wilting process uses solar energy to remove moisture prior to the actual drying process. This technique is used frequently in many locations in the United States and can result in appreciable energy savings.

In the current alfalfa-drying process the crop is harvested, loaded on a trailer, and conveyed to the alfalfa-drying site in a continuous operation. In field wilting, the harvested alfalfa is allowed to dry in the field for several hours and then is loaded and carried to the dehydrator. This interval during which the crop lies in the field after harvesting permits evaporation of appreciable quantities of moisture normally contained in the forage. Typically the interval between harvesting and processing is about 4 to 6 hours.

A danger that farmers face when this approach is used is rain during the interval between harvesting and collection of the crop. If it rains during this time, drying obviously does not occur and mildew and rotting result. Field wilting requires that the farmer harvest the crop at a time that may be less favorable from the standpoint of nutrition than would otherwise be the case. In addition, in the field-wilting approach the farmer must make two trips through the field, one to cut the crop and the second to collect it. Finally, there is a danger of "overdrying" by allowing the crop to remain in the field too long. If this occurs, the nutrient quality of the crop diminishes.

The potential energy savings in using this approach are great. Assume for a moment that field wilting results in a drop of moisture content from 75 percent to 60 percent. (This is the same drop as assumed in the previous case for mechanical drying.)

As in the previous case the total potential energy saving is 6×10^9 SCF of natural gas nationwide. This, of course, represents an upper bound since field wilting will not be universally practical. In this case there is a potential for a slight decrease in the cost of dehydrated product which is probably offset by the increased risks associated with field wilting as a procedure.

The capital investment required by the farmer to accomplish this procedure is minimal. Two passes through the field are required, of course, and this increases operating costs. Probably the most significant additional cost in using this technique is associated with loss of crop due to adverse weather conditions in the period of field wilting. If we assume that 10 percent of the crop is lost per year due to both weather and overdrying this would probably be made up by utilization of the large unused capacity currently in place. The increased cost would then be that associated with the purchase of additional raw alfalfa and would be a small increment in the total product cost. The marginal cost of alfalfa would diminish if this technique were practiced. We estimate that the cost will drop approximately 5 percent because of savings involved in the use of natural gas. The impact on the industry would be minimal. Timing could be almost immediate, depending on the educational and incentive programs introduced by government to foster this technique. The effect on the nutritional quality of the product would have to be monitored but probably could be held within acceptable bounds.

In sum, this technique is exceedingly promising. It provides great savings in natural gas with very little impact on the industry or the product. Furthermore from our analysis it appears that the price of the product to the consumer would drop if this approach became more widespread.

Case 6: New drying systems; conveyor dryer; alfalfa. This case considers the construction of an alfalfa dehydration facility designed with geothermal application in mind from the beginning. This is the design associated with Case 6 of Chapter 6 and consists of a conveyor dryer analogous to the New Zealand facility. This case has been examined in detail in Chapter 6 and need not be discussed in detail here.

If the seven existing facilities within 50 miles of geothermal resources were eliminated and rebuilt at four geothermal sites, the total production would remain the same (140,000 tons annually). The analysis of Chapter 6 indicates an increase in product cost of \$26/ton and a potential annual savings of 1.4×10^9 SCF of natural gas. As in Cases 1 and 3 it is doubtful that the state of the industry could support this type of impact on price although the impact on nutritional value is expected to be minimal based on the considerations discussed in Chapter 7 and the New Zealand experience.

Case 7: New drying systems; various dryers; crop combinations. This case anticipates the potential use of multicrop drying centers located at various places throughout the western United States. The drying centers are new installations coincident with appropriate geothermal resources. The crops which rotate through these drying centers are brought from surrounding agricultural lands to be processed at the centralized facilities. The design and concept of such facilities has been explained in detail in Chapter 10.

In the spirit of the earlier policy cases, the "maximum application" of multicrop drying centers is postulated. This would involve centers being located at various geothermal sites throughout the West with various locally grown crops flowing through each of the centers. The characteristics of this system are summarized below.

- Principal crops: alfalfa, potatoes, onions, apples, cotton

- Number of centers: ten considered most attractive

Based on our consideration of the capacity utilization of the potato-dehydration industry it is clear that for those crops where low-temperature air can be used in the processing and where crop storage does not present a problem, near-maximum utilization of a geothermal resource is possible.

The data in Chapter 10 show that potatoes are a major crop in the region of the proposed multipurpose centers and it is assumed that the combination of potatoes with other crops can be programmed through a center to provide for a well-capacity utilization of 90 percent. For the purpose of this examination it is assumed that each well has a capacity of 50×10^6 Btu's/hour. This assumption then leads to a utilization of 4.4×10^{11} Btu's/year at each well for a total of 4.4×10^{12} Btu's/year for the ten sites. This is the equivalent of 4.4×10^9 SCF of natural gas and nearly 10 percent of the energy used nationally in dehydrating the twelve crops considered in this study.

Assuming the low-temperature air (270°F) can be used for the dehydration process, the analysis of Chapter 5 indicates annual operating costs for the geothermally heated air of $570,000 per site. This translates to $1.30/million Btu's. This is a cost which is at or below the current cost of natural gas. If a five-mile pipeline were included in the geothermal costs, the cost would increase to approximately $1.60/million Btu's.

It is estimated that centers to provide this type of utilization could be in place within ten years. This alternative appears most attractive since it would have minimal impact on the dehydration industry and provide for substantial savings in fossil fuels.

Case 8: Management strategy; market substitution; alfalfa. As a final case we consider the situation where the substitution for conventional dehy may become either desirable or necessary as a result of severe curtailment in natural gas supply to the industry. The potential savings in natural gas by the elimination of this industry is about 15×10^9 SCF annually. This savings is of questionable value relative to the economic displacement that would result from a complete cutoff.

Our study indicates that the primary market for dehy is the poultry feed industry and that a major contribution of the dehy component is as a yellowing agent for egg yolks. In the area of feed for ruminants other features may be important. In many applications adequate substitutes are available--for example, marigold petals as a xanthophyll source in poultry feed. All of the nutrient qualities of dehy are not known with certainty, but the marginal status of the market would appear to indicate that it may not be an "essential" ingredient in the feeds that currently absorb the output of the industry.

If the industry were severely curtailed for one reason or another we would expect to see an increase in the production of sun-cured alfalfa for ruminant feed and the substitution of other xanthophyll sources in poultry feed. The overall national impact of such a substitution would not be expected to be large except in its impact on the dehy industry itself.

Analysis

As a set, the eight cases examined above present a number of interesting alternatives. Modifications to existing systems are of lowest cost, but of least consequence. Installation of new drying systems is expensive in terms of both total required investment and operating costs; however, the amount of gas saved is larger. In the case of the multicrop center, the savings become quite significant.

The market-substitution strategy (which would replace dehy entirely) represents an intervention into the market which may not be warranted. Sun curing alfalfa results in deterioration of the product and, of course, adversely affects the dehy industry. Of all the strategies considered, field wilting, followed by conventional drying, may be the best bet from the standpoint of saving natural gas. In this instance, careful control could result in minimum loss of nutritional qualities and, assuming that harvesting could be properly coordinated in terms of its timing, quite appreciable quantities of gas could be saved. Furthermore, this technique could be practiced across the country, not just in the West. If all dehy in the United States were handled this way, approximately 6×10^9 SCF of natural gas could be saved. The dehy industry would hardly be affected and the product would remain usable in its present applications.

Our conclusion, therefore, is that two approaches are worth following:

- Multicrop dryers using long-time, low-temperature drying systems

- Field wilting of alfalfa followed by conventional drying

In the next section we address the potential policies which might be followed to encourage these two developments.

Policy Modes

We considered several different approaches to the implementation of the most desirable drying systems. These were

- demonstration plants
- market stimulation
- subsidies
- changing cost of competing energy sources
- regulation

Since the economics of the multicrop dryer are largely theoretical, a demonstration plant might well be a useful technique. This plant would be located near a developed geothermal resource and operated by a cooperative consisting of companies from the drying industries affected by the concept. For example, if alfalfa, potatoes, and onions were the crops included, dryer operators from each of these areas would be invited to contribute to the demonstration-plant experiment. They would become the operators in much the same way as utility companies operate electric-generation demonstration plants. Because of the cost and the uncertainties involved in retrofitting, the contribution of the government to the demonstration plant might be a major portion of the total capital expenditures.

There is, of course, no "demonstration plant" that can be associated with the field-wilting approach. Nevertheless, large-scale demonstration could prove useful. Field wilting is a technique currently practiced in several areas. One type of demonstration plant which might be particularly attractive and have important downstream consequences is an alfalfa-processing plant designed to produce protein and other alfalfa byproducts for human consumption. We have in mind a process similar to the Pro-Xan program explained in an earlier chapter and currently under study by USDA and in France. In a world seriously in need of food, the process might prove exceedingly valuable. Our analysis indicates that geothermal fluids could provide an appropriate energy source for such processes.

Market stimulation constitutes another policy mode. By market stimulation we mean government action which results in an increasing market for the dried agricultural product produced by a desired configuration. For example, the government might elect to purchase and store dehydrated alfalfa produced in dryers using geothermal fluids as an energy source. Such dried product might be used in the PL 480 program or might serve as an element of domestic agricultural policy--for example as a government-subsidized feed. In this application, the dried alfalfa could be a means of adjusting consumer meat prices.

Direct subsidies might be considered as a means of encouraging the development of the favored configurations. For example, the affected drying industries might be encouraged to participate in developing and using multicrop dryers through government subsidies which would, in effect, guarantee that the drying operations would not have operating costs higher than those currently experienced.

As for the field-wilting approach, no subsidies would be required since this operation is cheaper than the one it replaces. What would be required is some sort of guarantee program which would insure the farmer and the dryer against the possibility of adverse weather during the period of field wilting. This risk is potentially significant, and according to dehydrators who were contacted during the study, represents a major incentive to dehydrate artificially. An insurance program could be a major stimulant to the spread of field wilting prior to conventional drying.

Increasing the cost of competing energy sources may well happen without government action. In particular, removal of regulations controlling the price of interstate natural gas will have the effect of increasing the price of gas used by most dehydrators. In the western United States, a doubling of the price of gas would result in an increase of the price of dry alfalfa of 10 percent. In itself this will not be disastrous but it certainly would provide an added incentive to move toward field wilting, followed by conventional drying or sun curing.

Perhaps the most significant incentive to the development of new drying modes is the lack of availability of natural gas through regulation resulting in curtailment. In this instance, there will be an important incentive in the West to develop multicrop dryers using geothermal energy, and solar drying techniques. Once the curtailment occurs it will be too late to initiate a program; therefore, in view of this possibility (curtailments have already interfered with the production of dehy) some government action should move forward.

Recommendations

In view of this analysis, we believe that the government should

- proceed with the preliminary design of multicrop drying apparatus in conjunction with a developed geothermal resource, probably in the Imperial Valley.

- view this multicrop drying center as a demonstration project to be performed cooperatively with the drying industries which would be most affected by the new design.

- consider funding a major portion of the demonstration plant since, short of actual or threat of curtailment, there seems to be little incentive for drying industries to move to geothermal energy sources.

- carefully explore the energy saving that could be realized through field wilting of alfalfa, followed by conventional drying. This approach requires little capital investment and could be followed simply by changing the timing of harvest and drying.

- encourage field wilting of alfalfa followed by conventional drying as a more normal operating procedure by investigating means for establishing insurance programs which would help the farmer and a dehydrator guard against crop loss due to adverse weather during the critical field-wilting period. Statistical programs can be used to determine the length and cost of such insurance programs versus the return expected in terms of energy savings.

Appendix A

CURRENT ALFALFA DEHYDRATION PROCESSES

CURRENT ALFALFA DEHYDRATION PROCESSES

The dehydration of alfalfa did not begin to be of commercial importance until the 1930s. Alfalfa dehydration plants are relatively small operations that receive fresh-cut alfalfa from the fields and dehydrate it in a rotary drum that is usually gas fired. Harvested alfalfa can also be processed by sun curing, but the sun-cured product generally contains only about 14 percent protein whereas the dehydrated product contains 15 percent to 20 percent protein and also retains more vitamin A. Generally, sun-cured hay is lower in protein because it is usually harvested at a more mature stage and more leaves are lost in the sun-curing process than in dehydration.

The first step in the alfalfa-dehydration process is the field operation of harvesting. At harvest time the standing alfalfa is mowed and chopped in the field and transferred to a dump truck. The truck carries the "chops" to the dehydration plant (usually less than ten miles away) where they are dumped onto a self-feeder which carries the chopped alfalfa into the dryer.

A dehydration plant consists of a dryer and auxiliaries as well as machinery for grinding, packaging, and storage. Dryer auxiliaries typically include the infeed conveyor, feeder, lift apron, blower motor, and primary cyclone. Additional equipment installed at most plants includes a pellet mill and machinery for addition of both oil and grease to reduce dust and antioxidants to promote storage. The type of dryer used depends on the size of the plant; type, cost, and availability of fuel, and other factors. There are at least four basic dryer types in use:

Tray dryers are the simplest types; in them, drying is discontinuous and some handling is required. Operation is at low temperatures of 140° to 150°C, but fuel consumption tends to be high. The tray drier is generally considered obsolete except for use on individual farms where its low price and simplicity have advantages.[1]

Conveyor dryers were formerly used for alfalfa dehydration in this country but their use has diminished in comparison with rotary drum dryers. Conveyor dryers were also used for dehydration of alfalfa and other grasses and grains in Western Europe and the United Kingdom.[1,2] There are many different types of conveyor dryers manufactured (also referred to as "band" or belt dryers) but most are low-temperature (250 to 300°F) systems. In the simplest configuration, cut alfalfa is fed onto a continuously moving belt which is perforated to permit the flow of heated air through the alfalfa. The material to be processed is fed onto the feed end of the moving conveyor by means of a variety of preforming and feeding machines. The reasons for the decline in popularity of the conveyor dryer for alfalfa dehydration are not clear, although earlier designs were of small capacity. Because of its low-temperature operation, the conveyor dryer is ideally suited for low-level heat-recovery operations.

Pneumatic dryers are used in Europe and are adapted to factory conditions, the alfalfa being moved by forced air. The temperatures used are high, 500 to 1000°C, and the output is high. The pneumatic principle may be combined with a revolving drum in some installations.[1]

Single-drum dryers are constructed with a rotating drum and baffles to keep the alfalfa agitated and exposed to the drying air. This is usually a direct-fired system in which heated gases evolved from combustion of either oil or natural gas contact the alfalfa directly. As the drum rotates the alfalfa is dropped through the hot gases, giving off moisture. The material is advanced through the dryer by means of a suction fan and the action of the baffles (also called "flights"). Alfalfa and drying air both enter the same end of the dryer in cocurrent fashion. Temperatures vary from about 800°C at the inlet to about 125°C at the outlet. The alfalfa is typically dried in 5 to 8 min.[1]

Multiple-drum dryers are similar in appearance and operation to the single-drum type, except that the drum is divided into three concentric cylinders. 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 effective length of the dryer is increased, and lower outlet temperatures can be achieved than with the single-pass dryer.

Both single-pass and triple-pass dryers are widely used in this country. The largest rotary-drying equipment currently manufactured is a Sterns-Roger drum capable of evaporating 80,000 lb of water per hour. A typical dehydration facility would include two triple-pass drums each capable of evaporating 18,000 to 20,000 lb of water per hour and consuming 30 to 35 million Btu's per hour. An installation of this type could produce approximately 16,000 tons of dehydrated alfalfa per season utilizing green-chop or 22,000 tons utilizing field-wilted alfalfa.[3]

Auxiliary equipment used for alfalfa dehydration includes field equipment and other processing equipment required for dryer operation, as well as special equipment required to maintain uniform product quality. Field equipment includes machinery to mow and chop the crop and blow it into trailers for transportation to the drying plant. A dehydration plant consists essentially of a dryer, machinery for grinding and pulverizing the dried product, and provision for packaging and storage. Equipment sold as part of the dryer system sometimes includes a blower, primary cyclone, and product cooler.

Special equipment may be required to produce a special product or to reduce labor. Blenders are necessary to ensure uniformity, as different lots of alfalfa may vary in protein and carotene content. Cooling devices to be used before the meal is sacked will help to preserve carotene. Shredders break down stemmy material and speed up the dehydration process. Automatic sackers reduce labor, especially as bulk handling of dehydrated products is not a common practice in the industry. Pelleting equipment and equipment for adding vegetable oil to eliminate dust have been considered as special, but are rapidly being regarded as standard requirements. These types of special equipment, and others that are continually being developed, are undoubtedly adding to the overall cost of production. However, they do guarantee uniformity and a product that will meet specifications and, in this way, add to attractiveness and increase the confidence of the consumer.[1]

The alfalfa dehydration industry in this country is moving from several small dryers to one or two large dryers of the drum type at each installation.[3] A generalized process flow sheet is shown in Figure A.1.

The drying drum usually is fired with either natural gas or oil. Combustion air flows into the drum by the induced-draft fan (primary blower) as shown in Figure A.1. The temperature at the drum inlet is about 1800°F and the outlet is approximately 275°F. Drums may be single-pass or triple-pass. Subjecting the alfalfa to the hot gases in the drum evaporates the water to dehydrate the alfalfa from its original moisture content of about 80 percent down to 8 to 10 percent. The exhaust gases have a high moisture content (30 percent) and also entrain the finer particles of alfalfa. The effluent may also contain odors from volatile matter driven off the alfalfa in the drying process.

The high-moisture gases and dry product from the drum enter the primary cyclone, which separates the product from the gases. The moisture-laden gases discharged to the atmosphere represent the first and perhaps the largest source of particulate emissions. In some plants the fan or blower is between the drying drum and the primary cooling cyclone (referred to as a positive-pressure system). In other plants the blower may be located in the outlet line from the primary cooling cyclone (negative-pressure system).

The material separated in the primary cyclone next enters the grinding machine, normally a hammermill. The grinder reduces the dehydrated chops to a powder referred to as "meal." From the grinder the meal enters the negative pneumatic conveyor that discharges into the meal-collection cyclone. The cyclone is intended to separate the meal from the conveying air and to accumulate the meal in the meal bin feeding the pelletizing system. In some plants, the air from the meal-collection cyclone is drawn through a fan and discharged into the secondary meal-collection cyclone in an attempt to recover meal that escapes the first meal collector.

The meal accumulated in the meal bin is fed through a steam conditioner prior to entering the pellet mill. The pellets from the mill are pneumatically conveyed to the primary pellet-collection cyclone from which they are fed into the pellet cooler. The air exhaust from the primary pellet-collection cyclone enters a fan and may be discharged through a secondary pellet-collection cyclone.

In the pellet cooler a flow of ambient air is drawn through a downward-moving column of pellets to cool the pellets prior to bagging or transport to bulk storage or bulk loading. The air from the pellet cooler picks up some moisture and heat from the pellets. This air is discharged through a fan to a pellet-cooler cyclone.

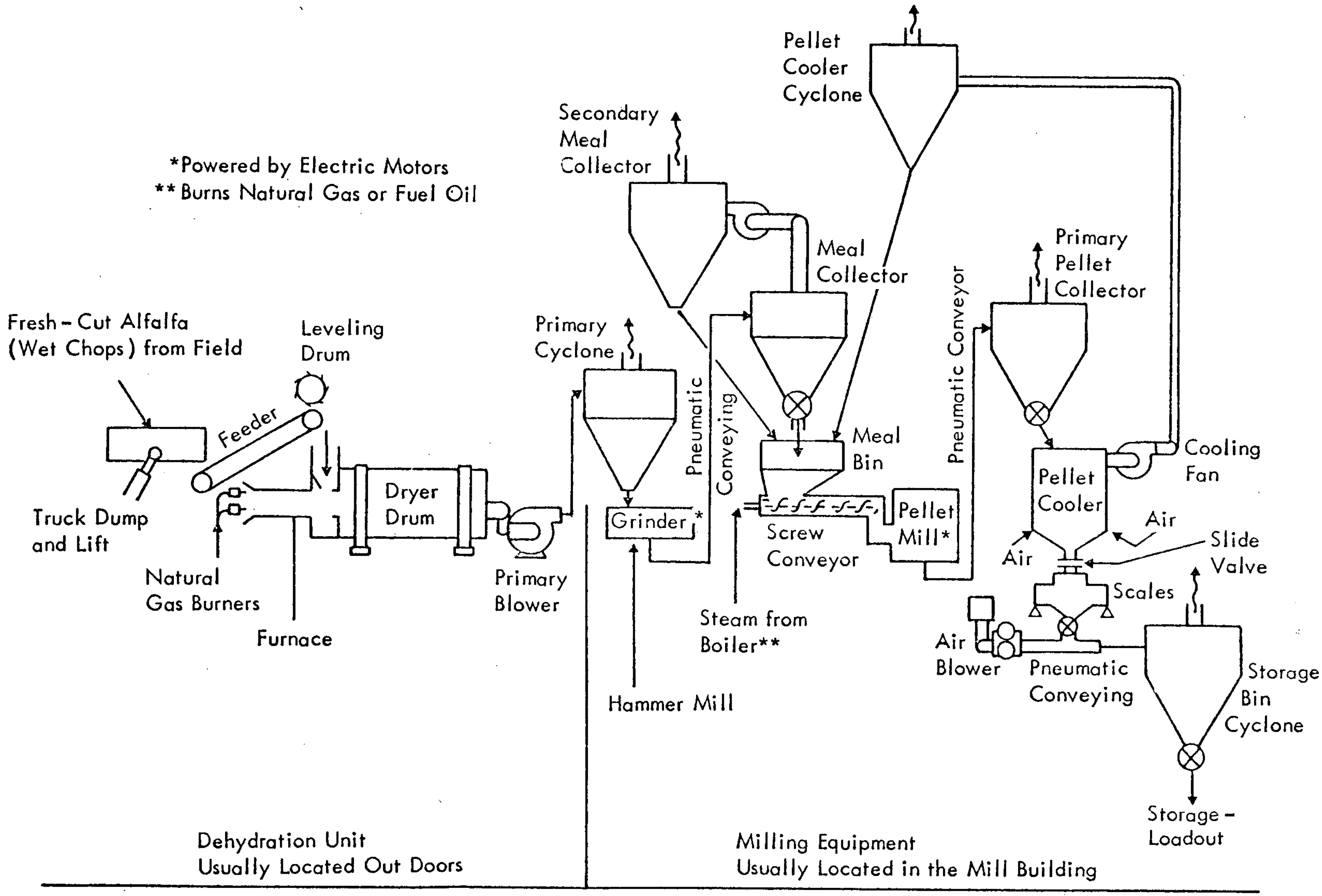

Figure A.1. Generalized Process Flow for Alfalfa Dehydration

The process flow described above and depicted in Figure A.1 is a general example for an alfalfa-dehydrating plant. However, there are several variations in the process scheme that are used. For example, the pellets from the pellet mill may be mechanically conveyed to the pellet cooler, thereby eliminating the pellet-collection cyclones.

In the typical alfalfa-dehydrating process, energy inputs consist of both electrical energy and natural gas or oil. Electrical energy usage is estimated at 120 Kw-hr/ton of dehydrated alfalfa (thermal equivalent is 0.41 million Btu's/ton, which is about 3.5 percent of the total energy requirement). Fossil energy requirements vary widely with feed-moisture content and dryer design. Production averages compiled by the American Dehydrators Association indicate that about 11.1 million Btu's of natural gas are required per ton of product.[4] Thus, for the rotary dryer the major portion of the energy consumed is fossil fuel.

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Appendix B

GEOCITY ASSUMPTIONS AND SAMPLE COMPUTER RUN

Table B.1

GEOCITY ASSUMPTIONS COMMON TO ALL CASES

RESERVOIR CHARACTERISTICS

- Average Depth	2000.0	Meters
- Average Temperature	182.2°	C
- Producing Capacity	275.0	MW(E)

WELL DESIGN (AVERAGE)

- Depth	2000.0	Meters
- Bottom Diameter	22.225	Centimeters
- Fraction Cased	100	%

WELL PROPERTIES (AVERAGE)	100	%
- MW(TH)/Well	146.2	
- Maximum Flow Rate/Well	440,000.0	Pounds/Hour
- Well Life	10.0	Years
- Input Well Spacing	20.0	Acres
- Flow Rate/Well (Actual)	318,964.0	Pounds/Hour
- Well Pressure at Saturation	153.0	PSIA
- Fraction Steam (Wellhead)	0.0	%

STRATIGRAPHY

- Rock Type	Hard	
- Depth	2000.0	Meters

FLUID COMPOSITION

- $CaCO_3$	0.00 %
- NaCl	1.40 %
- SiO_2	.03 %
- Other	0.00 %
- Total Dissolved Solids	1.43 %

- PH = 7.00

NONCONDENSIBLE GASES

- H_2S	0.000 %
- CO_2	.048 %
- CH_4	0.000 %
- Other	0.000 %
- Total Noncondensible Gases	.048 %

RESERVOIR ECONOMIC DEVELOPMENT FACTORS

- Percent Nonproducing Wells	20.0
- Fraction Excess Producing Wells	.20

Table B.1 (Cont.)

GEOCITY ASSUMPTIONS COMMON TO ALL CASES

ECONOMIC ASSUMPTIONS

- Bond Repayment Proportional to Sum of Years Digits Depreciation		
- Project Life	20	Years
- Fraction of Initial Investment in Bonds	19	%
- Bond Interest Rate	8	%
- Equity Earning Rate (after Taxes)	15	%
- Federal Income Tax Rate	48	%
- Depreciable Life of Wells	10	Years
- First Year of Operation	1980	
- State Income Tax Rate	9	%
- State Gross Revenue Tax Rate	0	
- Property Tax Rate	2.32%	
- Disposal System Replacement Rate	9	%
- Transmission System Replacement Rate	9	%
- Property Insurance Rate	0.19%	
- Royalty Payment	10	%
- Plant Operating Life	10	Years
- Transmission System Maintenance Rate	5	%
- Disposal System Maintenance Rate	5	%
- Drilling Cost per Producing Well	300,000	Dollars
- Drilling Cost per Nonproducing Well	300,000	Dollars
- Drilling Cost per Injection Well	300,000	Dollars
- Percentage Investment Tax Credit	10	

Table B.2

DISTRIBUTION OF ENERGY COSTS*

	CENTS PER MILLION BTU'S	ANNUAL COST
Field Identification and Exploration**	27.6	$ 120,600
Field Development (Total)	128.0	559,250
- Producing Wells	38.8	169,400
- Transmission System	64.1	280,090
- Disposal System	25.1	109,760
- Nonproducing Wells	0.0	0
Field Operating Costs (Total)	89.4	390,620
- Disposal Costs	13.6	59,360
- Producing Wells	3.4	15,000
- Transmission Costs	45.5	198,640
- Other Operating Costs	26.9	117,630
Revenue Taxes	0.0	0
State Income Taxes	9.2	40,400
Royalty Payments	33.0	144,270
Federal Income Taxes	36.5	159,290
Bond Interest	6.5	28,260
By-Product Revenue	0.0	0
Totals	330.3	$ 1,442,680

*10% Investment Tax Credit assumed; Geocity Case 2.

**These costs were subtracted from the total costs and 10 cents per million Btu's was added to the costs per million Btu's to yield the costs shown in Table 9.4.

Appendix C

DEHYDRATING INDUSTRY DESCRIPTIONS AND ENERGY USE

Table C.1

ARIZONA: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	≤50 miles
Alfalfa	One dehydrator, located Yuma County.	40	--
Sugar beet pulp[1]	One beet sugar factory, located town of Chandler, Maricopa County.	550	550
Rice	None	--	--
Cotton[4]	Within 50 miles are 42 gins in Maricopa County (70×10^9 Btu's/yr), 5 gins in Cochise C. (6×10^9 Btu's yr), 36 gins in Pinal C. (55×10^9 Btu's/yr) and a few others in Greenlee and Graham Counties. Also 19 gins in counties of Yuma, Pima (8), Mohave (1)	170	130
Potatoes	None	--	--
Apples	None	--	--
Peaches, Pears, Apricots	None	--	--
Prunes	None	--	--
Raisins	None	--	--
Onions	None	--	--
Garlic	None	--	--
Chilis, Other Vegetables	None known; may be plant(s) in Cochise County, which grows chilis.[14]	--	--
Total	All industries	760	680

Table C.2

CALIFORNIA: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	≤50 miles
Alfalfa	Probably 4 operating plants in 1977: Dixon (200 X 10^9 Btu's) Firebaugh (300 x 10^9 Btu's), El Centro (400 x 10^9 Btu's), Holtville (250 x 10^9 Btu's).	1100	1100
Sugar beet pulp [1]	7 plants within 50 miles, in Brawley, Clarksburg, Hamilton City, Mendota, Santa Ana, Spreckels, Woodland; 3 others.	5700	3500
Rice [3]	18 commercial dryers, all within 50 miles of geothermal resources, were identified in Butte, Yolo, Merced, Colusa, Fresno and Glenn Counties.	250	250
Cotton [4]	Of 211 gins active 1977-8, 105 are less than 50 miles from geothermal resources, in Riverside, Imperial, Kern, Madera, Merced, and Fresno Counties.	860	350
Potatoes	None	--	--
Apples [9]	4 large and 2 smaller dehydrators located in Sebastopol (Sonoma County) and Santa Cruz C. All but small one in Santa Cruz C. are less than 50 miles from geothermal; the Sebastopol plants are about 10 miles south of The Geysers KGRA.	200	190
Peaches, Pears, Apricots [11]	Some prune, raisin and apple dehydrators dry small amounts of these fruits, probably in Sonoma and Santa Clara Counties and the Sacramento Valley in general.	15	7
Prunes [12]	Over 200 dryers are located in Santa Clara, Sonoma, Colusa, Solano, Butte, Sutter, Yuba, Napa and Tehama Counties. Of the largest 15 dryers, all but one is located within 50 miles of a resource.	1300	1200
Raisins [15]	14 larger dehydrators and 8 small ones are located in Kern, Madera, Fresno, Tulare, Stanislaus and Merced Counties; 4 of the larger ones are less than 50 miles from resources.	300	100
Onions [16]	About 6 plants, located in Solano, Stanislaus, Santa Clara and Merced Counties; 4 within 50 miles of geothermal..	1500	1000
Garlic [18]	6 plants, of which 5, located in Solano, Monterey, Santa Clara and Merced Counties, are within 50-mile radius of geothermal.	300	250
Chilis, Other Vegetables [19]	4 plants, located in Stanislaus, Ventura (near Sespe H.S. KGRA), and Santa Clara Counties produce dehydrated chili, carrots and other vegetables. 2 of the plants are within the 50-mile radius.	130	60
Total	All industries	12,000	8000

Table C.3

COLORADO: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	≤ 50 miles
Alfalfa[2]	About 16 plants, mostly in Weld and Prowers Counties, 2 plants about 45 miles from Idaho Springs.	1000	120
Sugar beet pulp[1]	2 plants within 50 miles: at Johnstown and Loveland, 6 other operating plants.	5000	1200
Rice	None	--	--
Cotton	None	--	--
Potatoes[6]	2 plants producing starch and flakes located in Monte Vista, Rio Grande County, about 25 miles west of Alamosa County KGRA.	450	450
Apples	None	--	--
Peaches, Pears, Apricots	None	--	--
Prunes	None	--	--
Raisins	None	--	--
Onions	None	--	--
Garlic	None	--	--
Chilis, Other Vegetables	None known; may be plant(s) in Pueblo County, which grows chilis.[14]	--	--
Total	All industries	6500	1800

Table C.4

IDAHO: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	≤50 miles
Alfalfa	1 operating plant, in Twin Falls, about 12 miles from the Cedar Hill geothermal area.	100	100
Sugar beet pulp[1]	4 plants, all less than 50 miles, in Nampa (1150 x 10^9 Btu's), Twin Falls (600 x 10^9 Btu's), Mini-Cassia (900 x 10^9 Btu's), Idaho Falls (600 x 10^9 Btu's).	3200	3200
Rice	None	--	--
Cotton	None	--	--
Potatoes[6]	At least 15 plants are in the Snake River Valley in Bingham, Bonneville, Canyon Cassia, Elmore, Jefferson, Madison, Minidonka and Power Counties. Only 2 are more than 50 miles from geothermal; 1 is only 5-10 miles SE of Mountain Home KGRA.	4200	3800
Apples	None	--	--
Peaches, Pears, Apricots	None	--	--
Prunes	Prunes are grown in Canyon, Gem, Owyhee, Payette and Washington Counties,[14] but apparently are not dried in Idaho.	--	--
Raisins	None	--	--
Onions	None	--	--
Garlic	None	--	--
Chilis, Other Vegetables	None	--	--
Total	All industries	7500	7100

Table C.5

MONTANA: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	$\leq$50 miles
Alfalfa	None	--	--
Sugar beet pulp[1]	2 plants, in Billings and Sidney.	1200	--
Rice	None	--	--
Cotton	None	--	--
Potatoes	None	--	--
Apples	None	--	--
Peaches, Pears, Apricots	None	--	--
Prunes	None	--	--
Raisins	None	--	--
Onions	None	--	--
Garlic	None	--	--
Chilis, Other Vegetables	None	--	--
Total	All industries	1200	0

Table C.6

NEVADA: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	≤50 miles
Alfalfa	None	–	–
Sugar beet pulp	None	–	–
Rice	None	–	–
Cotton [4]	1 active gin 1977-8, located in Pahrump, southern Nye County. Production probably 10,000 bales/yr. plus or minus 50%.	2	–
Potatoes [6]	1 flake plant, located Humboldt County, in prospective geothermal resource area.	450	450
Apples	None	–	–
Peaches, Pears, Apricots	None	–	–
Prunes	None	–	–
Raisins	None	–	–
Onions	None	–	–
Garlic	None	–	–
Chilis, Other Vegetables	None	–	–
Total	All industries	450	450

Table C.7

NEW MEXICO: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	≤50 miles
Alfalfa[2]	2 plants, located Hagerman and Dexter, at least 150 miles from nearest geothermal area (Radium H.S.)	120	120
Sugar beet pulp	None	-	-
Rice	None	-	-
Cotton[4]	Of 41 gins active 1977-8, 20 are 50 miles from geothermal resources, in Dona Ana (16), Luna (3), Hidalgo (1) Counties. Those in Dona Ana and Hidalgo are very convenient to geothermal.	21	10
Potatoes	None	-	-
Apples	None	-	-
Peaches, Pears, Apricots	None	-	-
Prunes	None	-	-
Raisins	None	-	-
Onions	None	-	-
Garlic	None	-	-
Chilis, Other Vegetables[20]	10 chili dehydrators are located in Dona Ana and Sierra Counties, 15-35 miles from Radium H. S. KGRA.	250	250
Total	All industries	390	380

Table C.8

OREGON: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's Whole State	Annual energy use, 10^9 Btu's ≤50 miles
Alfalfa	No dehydration. One plant, at Irrigon in Morrow County, produces sun-cured alfalfa.	-	-
Sugar beet pulp[1]	One plant at Nyssa, near Vale H.S. KGRA.	850	850
Rice	None	-	-
Cotton	None	-	-
Potatoes [6]	One flake plant in Morrow County.	200	-
Apples	None	-	-
Peaches, Pears, Apricots[11]	No plants were recorded; however some prune dehydrators may process small amounts.[8]	-	-
Prunes [13]	There were 46 dryers, 20 operating intermittently, in 1970.[8]	14	1
Raisins	None	-	-
Onions	None	-	-
Garlic	None	-	-
Chilis, Other Vegetables	None	-	-
Total	All industries	1100	850

Table C.9

UTAH: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	≤50 miles
Alfalfa	None at present; one plant formerly in Delta.	–	–
Sugar beet pulp[1]	1 plant located in Garland about 40 miles north of Hooper H.S.	350	350
Rice	None	–	–
Cotton	None	–	–
Potatoes	None	–	–
Apples	None	–	–
Peaches, Pears, Apricots	None	–	–
Prunes	None	–	–
Raisins	None	–	–
Onions	None	–	–
Garlic	None	–	–
Chilis, Other Vegetables	None	–	–
Total	All industries	350	350

Table C.10

WASHINGTON: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	≤50 miles
Alfalfa	None at present; formerly 2 plants.	--	--
Sugar beet pulp[1]	2 plants: Moses Lake and Toppenish (about 500 x 10^9 Btu's/yr). Toppenish is 55 miles SE of Summit Creek Mineral Springs	1,100	--
Rice	None	--	--
Cotton	None	--	--
Potatoes[6]	3 plants in Moses Lake, Grant County; 1 in Franklin County. Produce flakes and granules. Nearest identified resources are 100 miles to the west.	720	--
Apples[9]	7 plants located in Yakima, Chelan and Okanogan Counties. 3 plants in Yakima County located 40-45 miles from Summit Creek Mineral Springs.	350	150
Peaches,[11] Pears, Apricots	About 1% of the production of one apple dehydrator is pears, probably in Yakima County.	2	2
Prunes	Prunes are grown in Yakima County[14] and may be dried by apple dehydrators. Any energy use for prunes is included with apples here.	--	--
Raisins	None	--	--
Onions	None	--	--
Garlic	None	--	--
Chilis, Other Vegetables	1 plant in Chelan County dries carrots.	10	--
Total	All industries	2,200	150

Table C.11

WYOMING: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole State	$\leq$50 miles
Alfalfa	None	--	--
Sugar beet pulp[1]	3 plants: at Lovell, Torrington and Worland.	2,000	--
Rice	None	--	--
Cotton	None	--	--
Potatoes[6]	1 plant east of Cheyenne, size and location not known: energy consumption shown is accurate to half-order-of-magnitude only.	100	--
Apples	None	--	--
Peaches, Pears, Apricots	None	--	--
Prunes	None	--	--
Raisins	None	--	--
Onions	None	--	--
Garlic	None	--	--
Chilis, Other Vegetables	None	--	--
Total	All industries	2,100	--

Table C.12

ALL OTHER STATES: DEHYDRATING INDUSTRY ENERGY CONSUMPTION

Crop	Description of Drying Industry	Annual energy use, 10^9 Btu's	
		Whole States	≤50 miles
Alfalfa	Approximately 200 plants: 77 in Nebraska, 40 in Kansas, 20 in Ohio, remainder in 15 other states.[23]	12,400	--
Sugar beet pulp[1]	20 plants located in Kansas, Michigan, Minnesota, Nebraska, North Dakota, Ohio, and Texas.	12,400	--
Rice	67,000,000 hundredweight, most of it split evenly among Texas, Louisiana and Arkansas, some in Mississippi and Missouri, in 1972.[10]	1,000	--
Cotton[21]	5.7 million bales were produced in 1975, mostly in Texas and Mississippi, and in 12 other states.	2,400	--
Potatoes[6]	6,100 x 10^9 Btu's in geothermal states dries 400 million lb.; energy estimate for 480 million lbs. dried in all U.S. (1975) proportional. Plants are in Maine, New York, Michigan, North Dakota, and Minnesota (1970).[8]	1,200	--
Apples[8]	2 plants (1970) dry undisclosed amount. Energy estimate based on average of cooperating Washington and Oregon plants ; plants are in New York State.	80	--
Peaches, Pears, Apricots	None	--	--
Prunes	Michigan produced 14,000 green tons in 1972 (Reference 10, Table 347): however, there were no dryers in 1970.[8]	--	--
Raisins	None	--	--
Onions	None	--	--
Garlic	None	--	--
Chilis, Other Vegetables	1 plant in each of Louisiana and North Carolina dries sweet potatoes.[8] Energy estimate is a guess.	10	--
Total	All industries	29,000	--

REFERENCES

1. TRW Systems and Energy, Use of Geothermal Heat for Sugar Refining, Final Report to ERDA/DGE, Report SAN/1317-3, May 1977. Energy use figures are for pulp drying only. Major energy source for pulp drying probably natural gas; coal and fuel oil are primary boiler fuels.

2. Assumes average annual output for one dehy plant is 6,000 tons (1,356,500 tons divided by 223 operating plants), using 60 x 10^9 Btu's. Probably 90% of fuel used is natural gas; remainder is fuel oil.

3. 160 x 10^9 Btu's were used in 13 plants that released figures in response to telephone requests, for an average use per plant of 12 x 10^9 Btu's. An additional 5 plants did not release figures; they are estimated to use 60 x 10^9 Btu's in all. These 18 plants are the major dryers; an additional 10-15% of rice is dried on farm. 250 x 10^9 Btu's is thus the approximate annual use, allowing for a few unidentified commercial dryers. About 8% of energy is propane; remainder is natural gas.[5]

4. Gin locations are from El Centro, CA, Bakersfield, CA and Lubbock TX Government Classing Office gin lists for 1977-8 season. County production figures were divided by the number of gins in the county to get average production per gin. These were then multiplied by a constant--1.94 x 10^5 Btu's/480-lb bale for Imperial County, CA and also for Arizona, New Mexico, Nevada and Riverside County, CA; 4.2 x 10^5 Btu's/bale for Tulare, Kern, Kings, Madeva, Merced, & Fresno Counties, CA--to yield energy estimates. Unit energy figures provided by Kevin Ernst, University of California Agricultural Extension, Davis, California over telephone. Natural gas and propane appear to be the main fuels used.

5. V. Cervinka, et al., Energy Requirements for Agriculture in California, Joint Study: California Department of Food and Agriculture, University of California, Davis, January, 1974. Tables 8, 9, 10, 24, 25, 26, 41-75.

6. Only starch, granule, flake, and slice and dice plants included; not included are frozen products or potato chip plants. Potato starch production requires approximately 15,000 Btu's/lb. starch; flake and granule production, at least 10,000 Btu's/lb. dry product. Whittlesey and Lee (Reference 7, Table 6) estimate that about 20,000 Btu's/lb. are required. It is likely that potato processing plants differ significantly in efficiency.

   12 of 15 Idaho plants released enough data to make good estimates of energy use; 3 of 4 Washington plants released sufficient data. For those that did not release data, the average energy consumption of the 19 cooperating plants in Colorado, Idaho, Nevada, Oregon, and Washington was used, 260 x 10^9 Btu's. Natural gas is the predominant heat source, but at least one plant, in Idaho, uses fuel oil full time; two plants, one each in Idaho and Oregon, use electric heat for drying.

REFERENCES (Cont.)

7. Norman K. Whittlesey and Chinkook Lee, "Impacts of Energy Price Changes on Food Costs," Bulletin 822 of College of Agriculture Research Center (Pullman, WA: Washington State University, April 1976).

8. E. D. White, "Dehydrated Foods in the United States," in W. B. Van Arsdel, M. J. Copley, and A. I. Morgan, Food Dehydration (Second Edition), Vol. I (Westport, CT: AVI Publishing Co., 1973), Table 2.3, p. 10.

9. Estimates for the energy required to produce one pound of dried apples vary from 5,000 to 14,000 Btu's (Reference 7 and letter from M. A. Davis, Sebastopol Co-operative Cannery, May 18, 1977, respectively) depending on product and dryer type. Therefore, the following procedure was used to estimate state energy consumption. California produced about 6.2 million pounds of artificially dried apples in 1972 (Reference 5); Washington about 10 million pounds (Reference 10, Table 298) assuming no Washington apples are sun-dried (about half of California dried apple production appears to be sun-dried). Good energy consumption figures were released by Washington plants; California energy use is assumed to be the same per lb of dried apples.

10. U.S.D.A., Agricultural Statistics 1973 (Washington: Government Printing Office, 1973).

11. Very few data are available for artificial dehydration of these fruits. Cervinka (Reference 5) suggests that in California, about 8×10^9 Btu's are used for apricot dehydration, 5×10^9 Btu's for peaches, and 2×10^9 Btu's for pears. Plant locations are not known precisely: 50% of them are assumed to be located less than 50 miles from a geothermal resource.

12. Sunsweet Dryers Co-operative consists of 15 plants that dried about 156,000 green tons of prunes in 1976. This represents about 40% of the California crop; the remainder is processed by about 200 dryers, most of them small. (Telephone conversation with office of Frank Dominic, Diamond-Sunsweet, Inc.) In all, about 360,000 green tons of prunes were dried in 1976. Energy estimates assume that the smaller plants are located within and outside of the areas less than 50 miles from geothermal in the same proportions as the larger 15 plants. 3.5×10^6 Btu's/green ton is assumed heat requirement for drying (telephone conversation with Mr. Dada, Dried Fruit Association; letter from Professor M. W. Miller, College of Agricultural and Environmental Sciences, University of California, Davis, May 16, 1977, which cites range of 2.6 to 5.0×10^6 Btu's/green ton).

13. Dryer location data was not collected. The estimates of energy use are based on assumptions that 4,000 green tons (Reference 10, Table 346) are dried annually at 3.5×10^6 Btu's/ton; that 10% of the dryers for this crop, which is grown predominantly in Yamhill and Umatilla Counties,[14] are less than 50 miles from geothermal resources.

14. U.S. Department of the Census, Census of Agriculture, 1969: Vol. I, Area Reports (Washington: Government Printing Office, 1972).

15. The 14 larger dehydrators, which processed about 75% of artificially dehydrated raisins (mostly the golden bleached variety), produced about 16-18,000 dried tons in 1976 (telephone conversation with Ed Hogt, U.S.D.A. Inspection Service, Fresno, CA). Four of these, in Madera, Kerman, and Sanger, are within 50 miles of resources. Energy estimates assume that the 8 smaller dryers are located within and outside of the areas less than 50 miles from geothermal in the same proportions as the larger 14 dryers; that 4.2 green tons are required to produce 1 dried ton; and that 3.5×10^6 Btu's/green ton are used.

16. Energy estimate for whole state based on 86.5 million lb. dried onions produced in 1970 (Reference 8, Table 2.6) at 17,500 Btu's/dried lb.[17] Estimate for plants within 50 miles is proportional: 67% of 6-plant energy use.

17. Telephone conversation with Mr. Mello, Gentry International, Inc., Dehydrated Vegetable Division, Gilroy, CA, May 19, 1977.

18. State estimate based on 21.9 million lb. dried garlic production in 1970 (Reference 8, Table 2.6) at 13,600 Btu's/lb. dried product.[17] Estimate for plants within 50 miles is proportional: 83% of 6-plant energy use.

19. In 1965, an estimated 30 million raw pounds of vegetables other than potatoes, onions, and garlic were produced (Reference 8, p. 15). About one-third were chilis, which probably account for about 2 million dried lb. in California. About 25,000 Btu's/dry lb. are required for chilis: 20,000 Btu's/lb. is assumed for 4 million dried pounds of other vegetables.

20. Energy estimate assumes that 5,000 dry tons of chili were dehydrated in 1975 (U.S.D.A. and New Mexico Crop and Livestock Reporting Service, "New Mexico Agricultural Statistics, 1975" [Las Cruces, NM: New Mexico Department of Agriculture, July, 1976] p. 31) at 25,000 Btu's/dried lb.

21. Production figures from U.S.D.A., Agricultural Statistics 1976 (Washington: Government Printing Office, 1976), Table 74. Energy consumption for drying assumed to be 4.2×10^5 Btu's/bale, as for San Joaquin Valley, CA (Reference 4), because climate is humid in most of the non-geothermal cotton states.

22. Agricultural Statistics, 1976, Table 247.

23. American Dehydrators Association, "Direct Members, Associate Members, Buyers Guide: 1976," (Mission, Kansas: ADA, 1976).

Appendix D

CONCEPTUAL DRYING CASCADES FOR MULTICROP DRYING CENTERS

Key

The drying season for each crop is shown as a horizontal bar. The temperature at the left of each bar is 5°C above the maximum air temperature required for the drying process for that crop; it gives a first approximation of the needed geothermal water temperature for the process.

Drying processes for each crop are arranged hierarchically by this temperature to give a preliminary geothermal water cascade for each MDC. One "cascade-month" is the use of outlet water from one drying process by the next drying process in the hierarchy for one month. (Further engineering study is needed to determine realistic heat exchanger inlet and return temperatures for each temperature level of the cascades.) Processes that differ by less that 5°C in the required inlet water temperature are grouped into one level in the hierarchy. Where resource temperature is lower than the inlet water temperature for the first drying process in the hierarchy, it is assumed that cascading is not possible.

Cascading from one process to others can only be done during the common part of the drying seasons for the crops; it is assumed that whenever such an overlap of two or more feasible processes exists, the water is cascaded from one to the next the maximum number of times over the entire overlap. Thus, the number of cascade-months is the sum of these re-uses of the geothermal water over time and gives a measure of the potential efficiency with which the MDC can extract energy for drying from the delivered geothermal water.

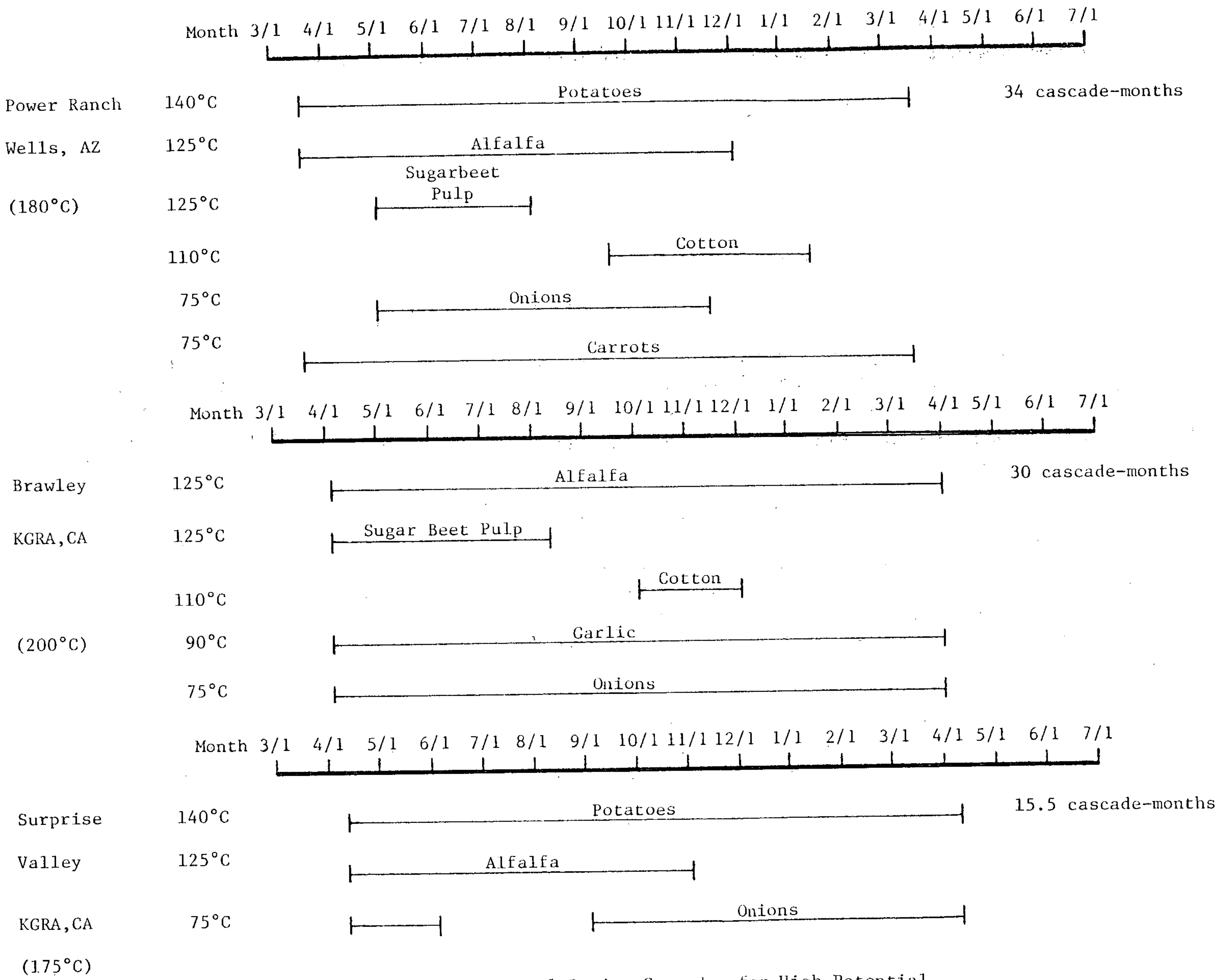


Figure D.1. Conceptual Drying Cascades for High-Potential Multicrop Drying Centers

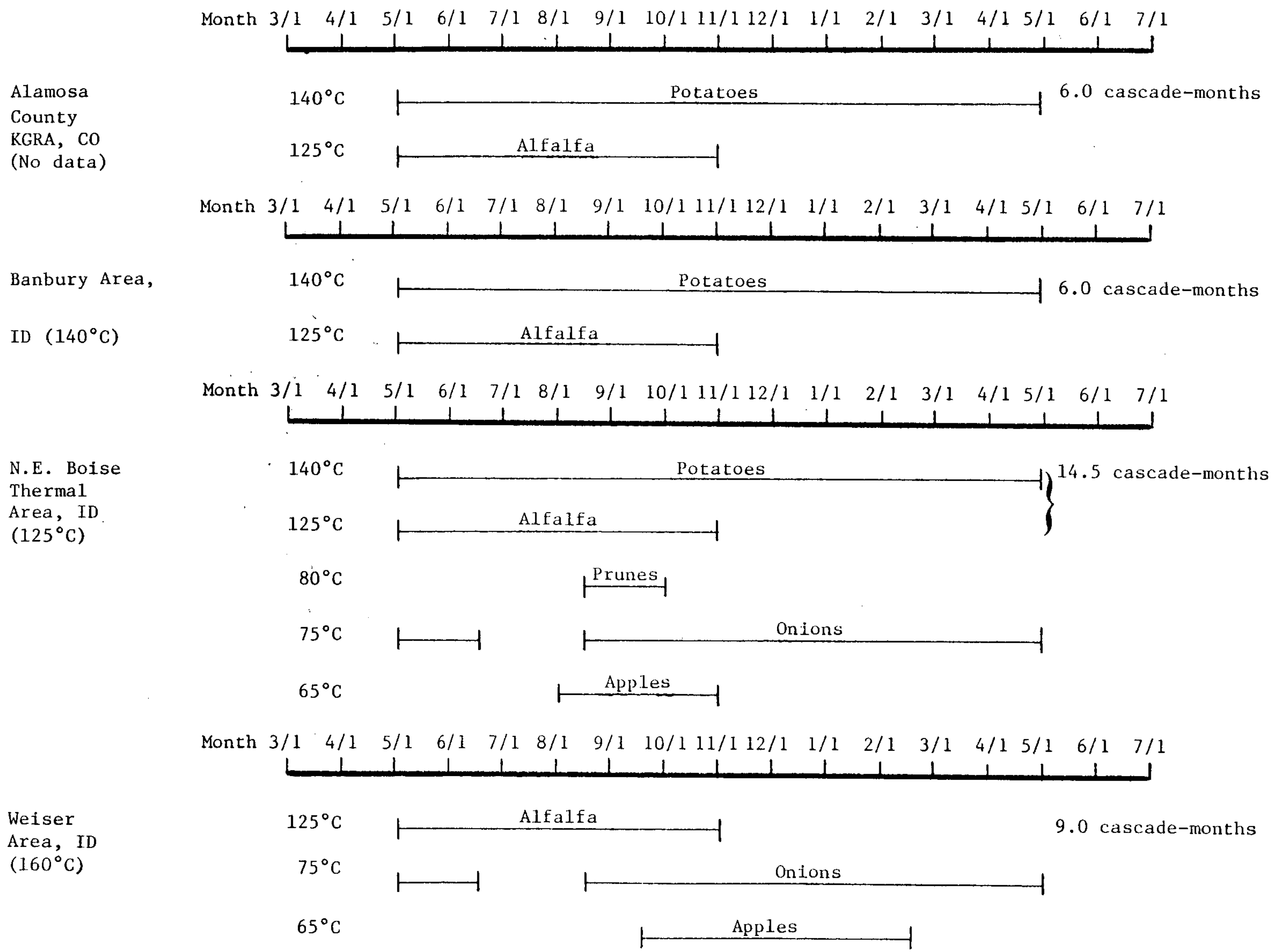
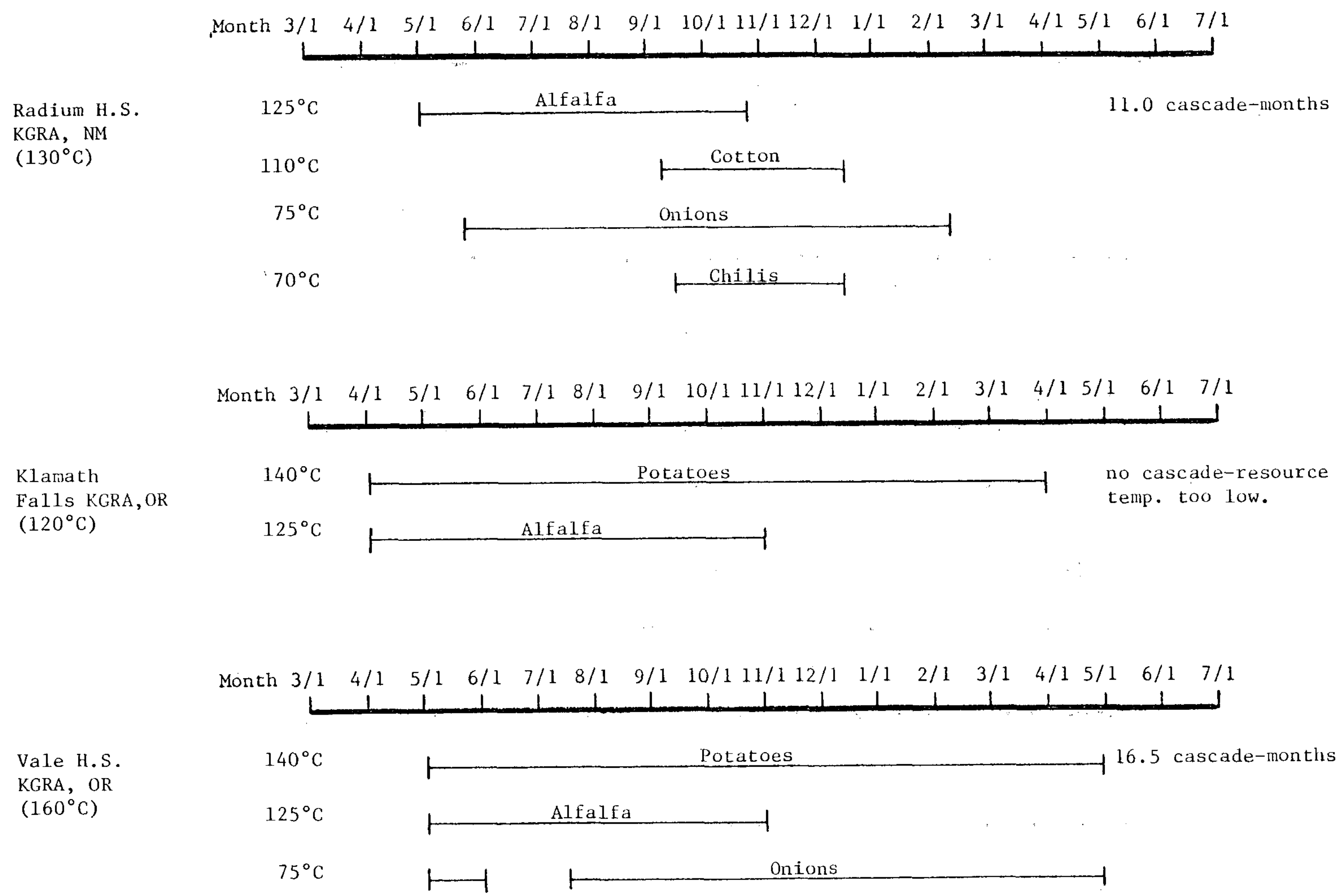


Figure D.1. (Continued)



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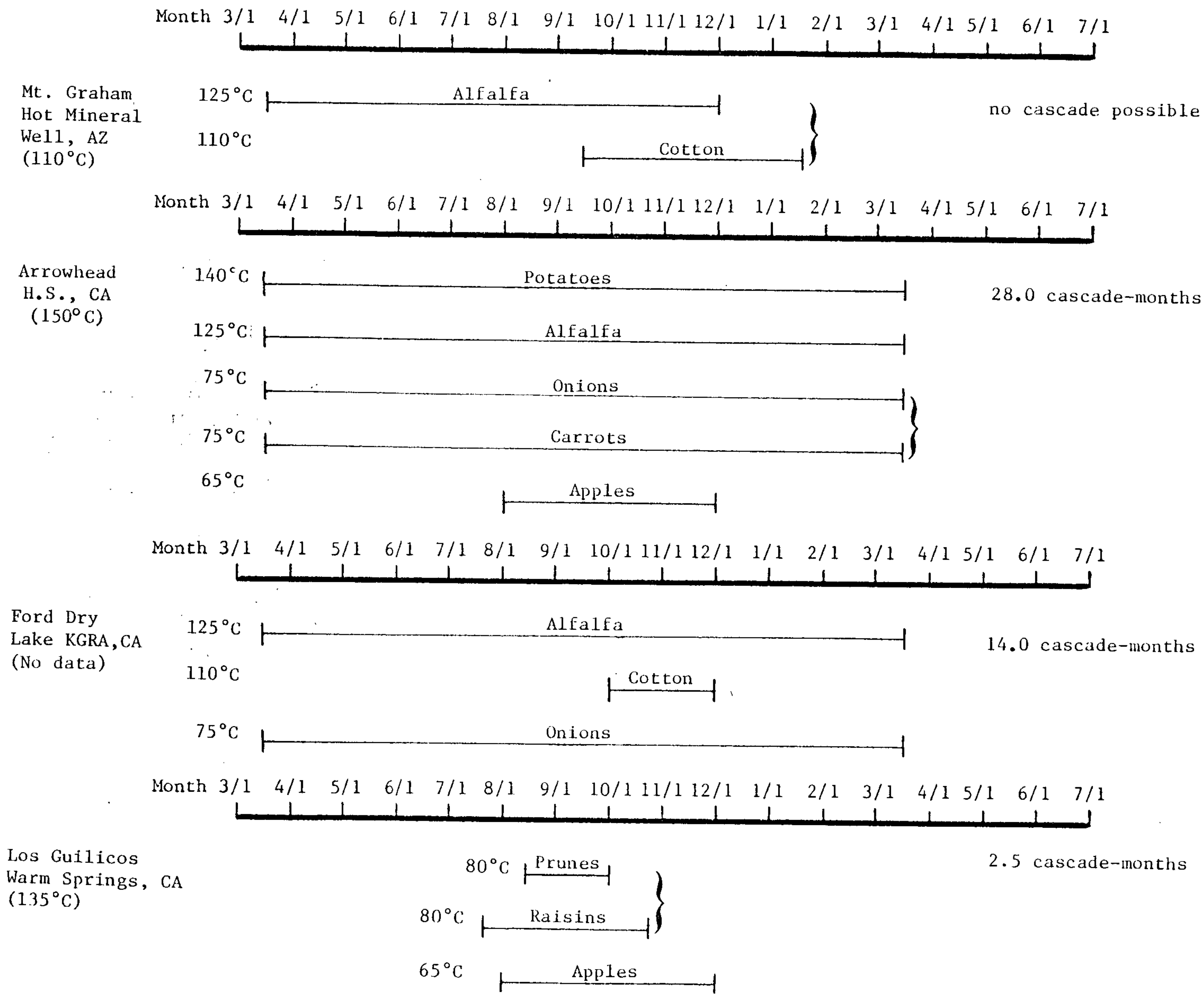
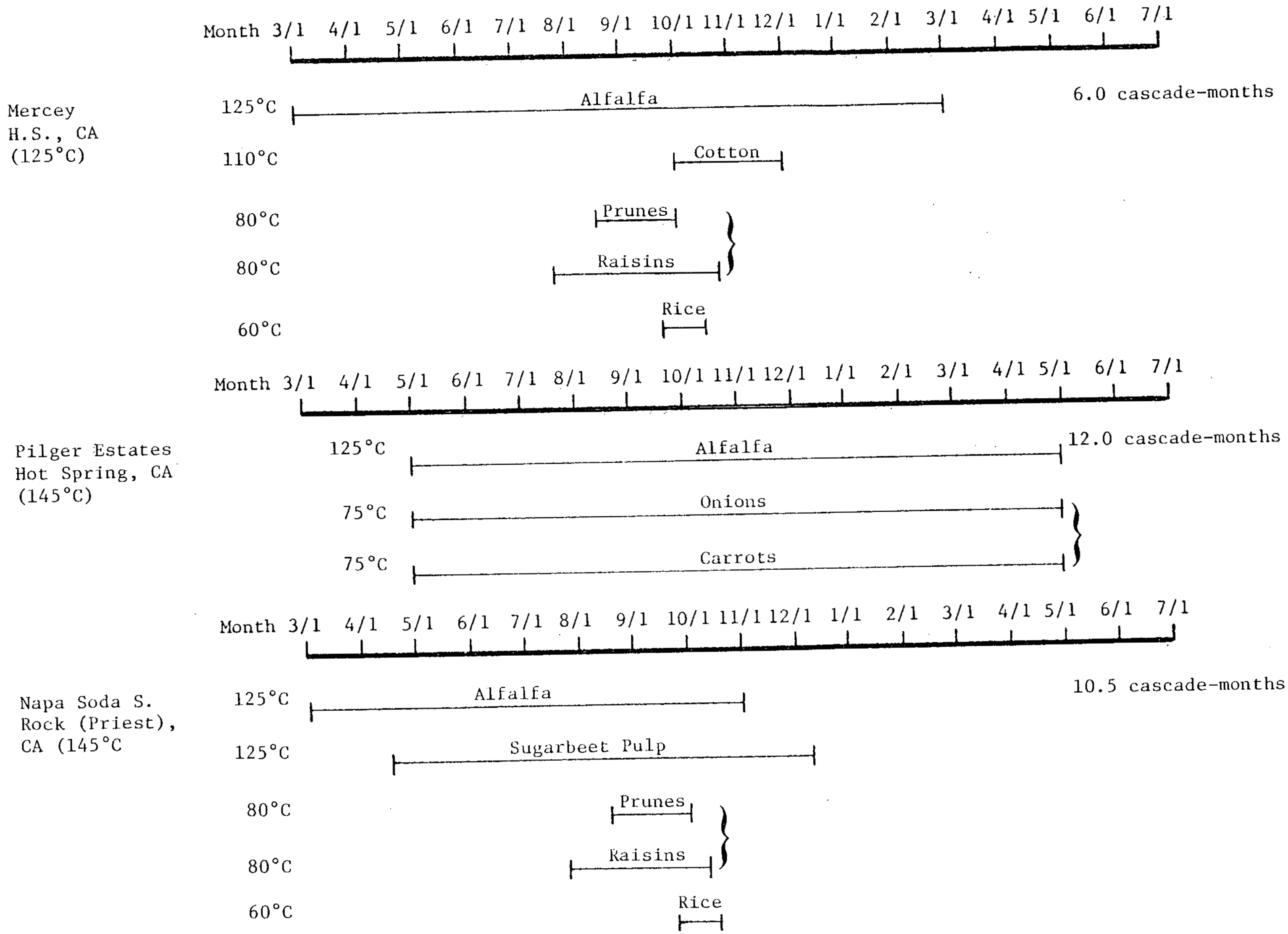


Figure D.2. Conceptual Drying Cascades for Medium Potential Multicrop Drying Centers



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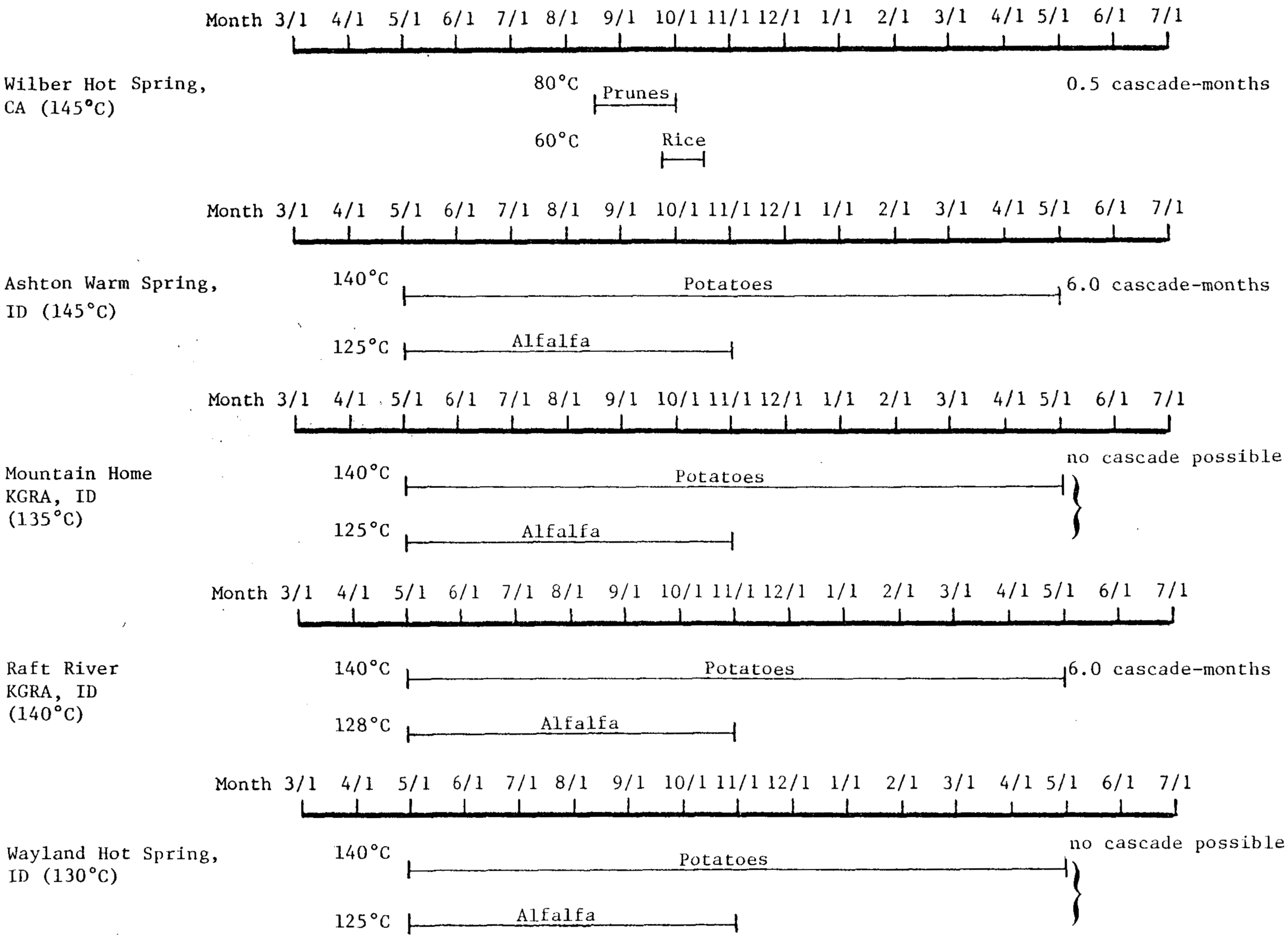

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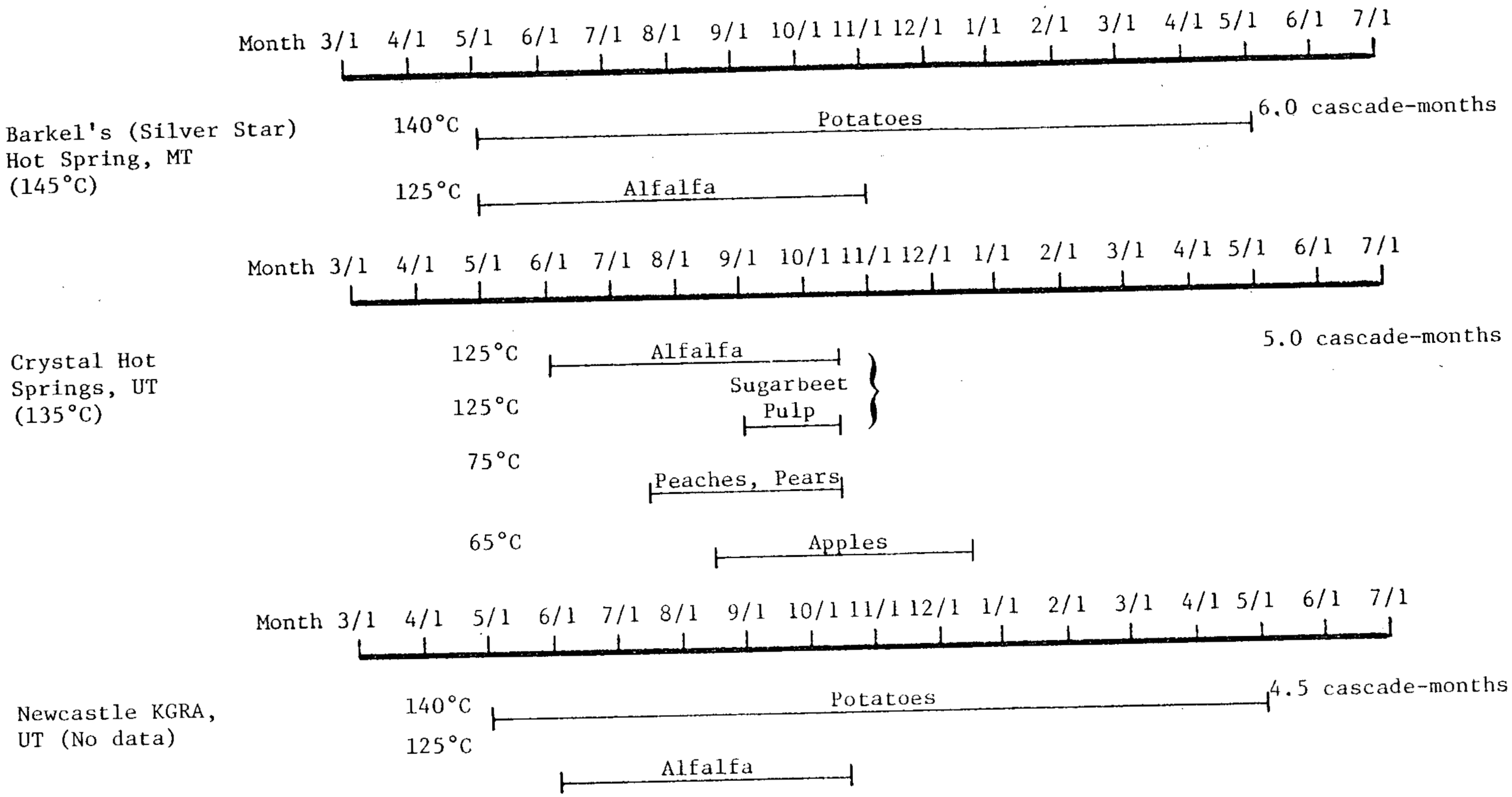

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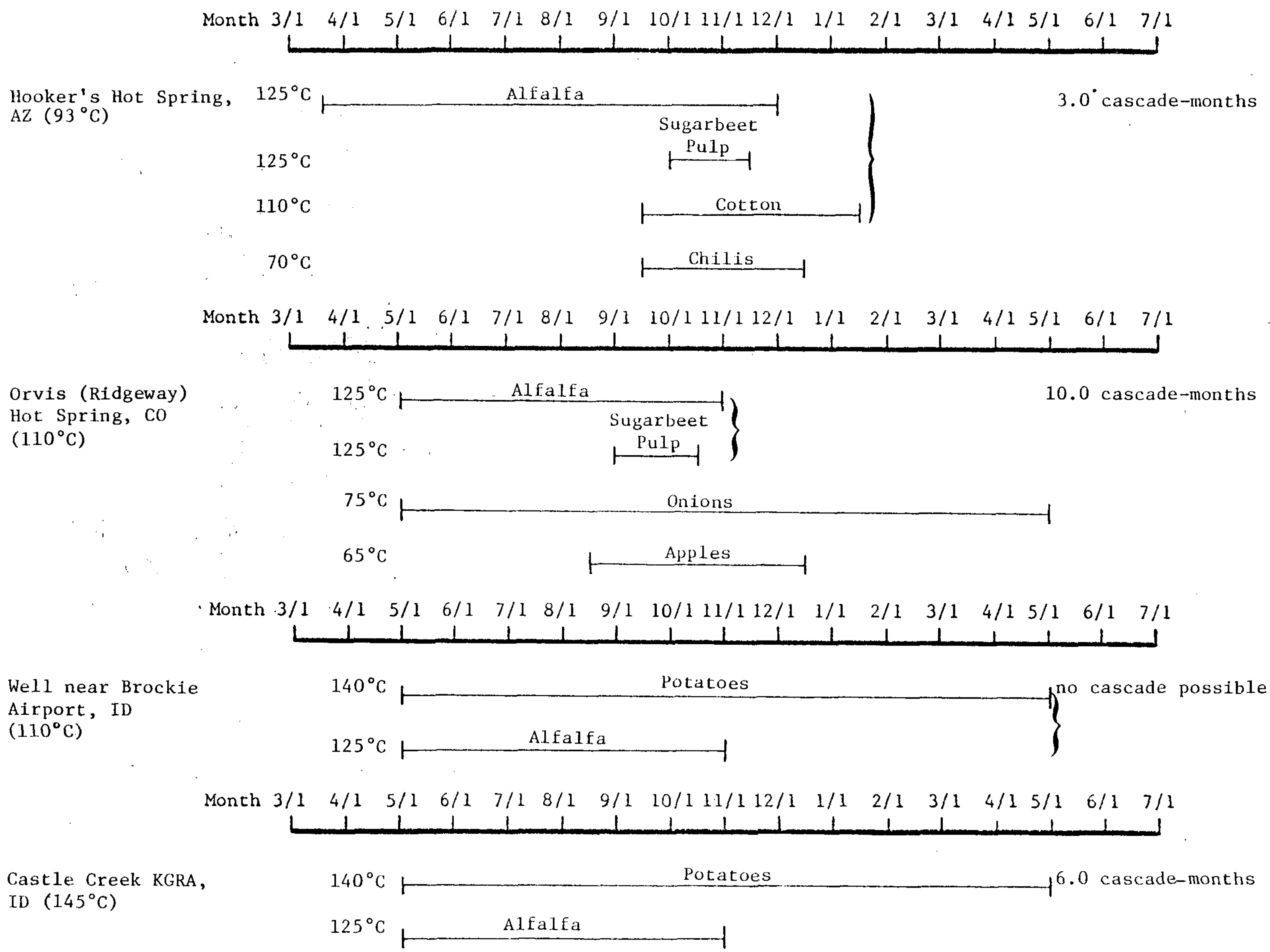
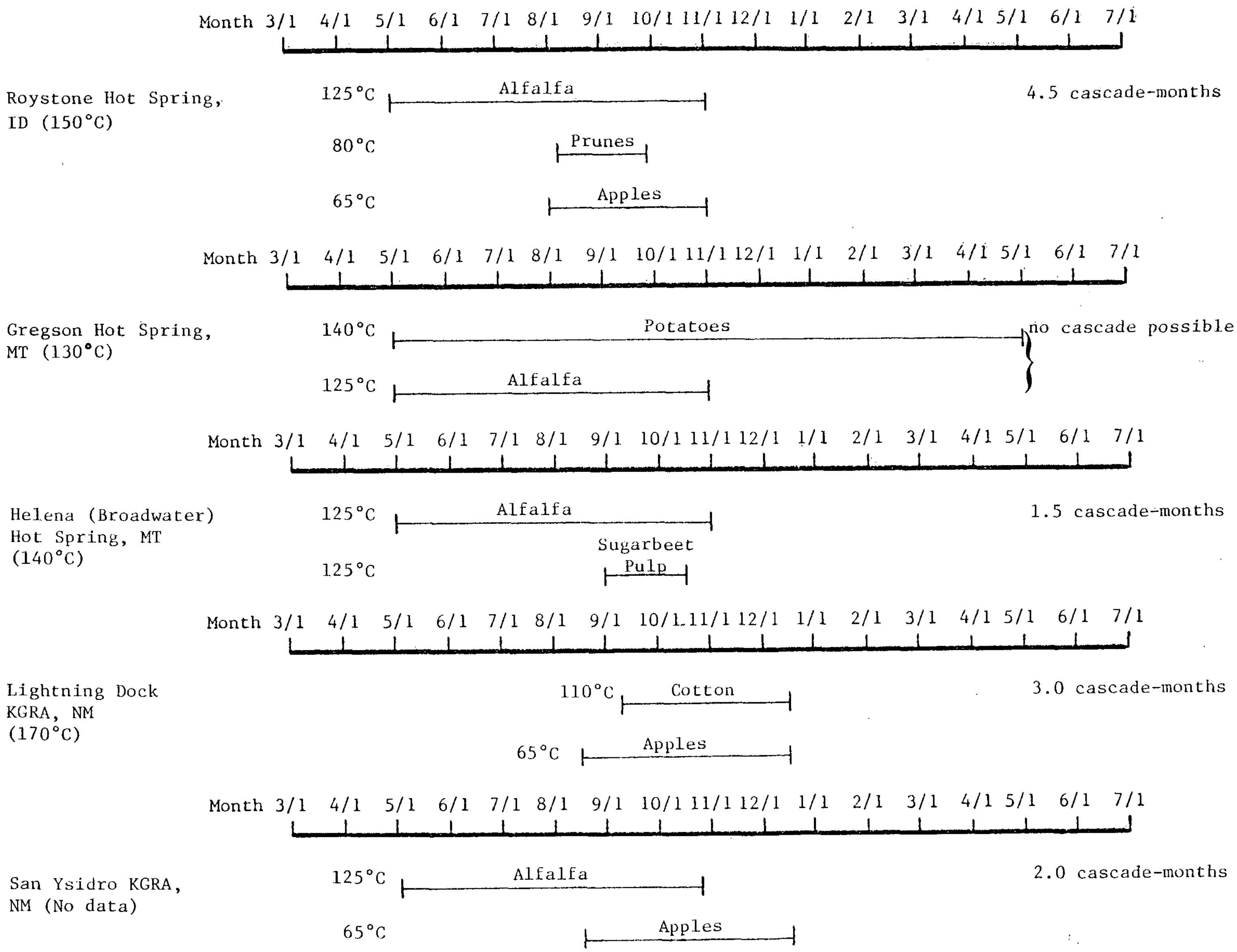


Figure D.3. Conceptual Drying Cascades for Low Potential Multicrop Drying Centers



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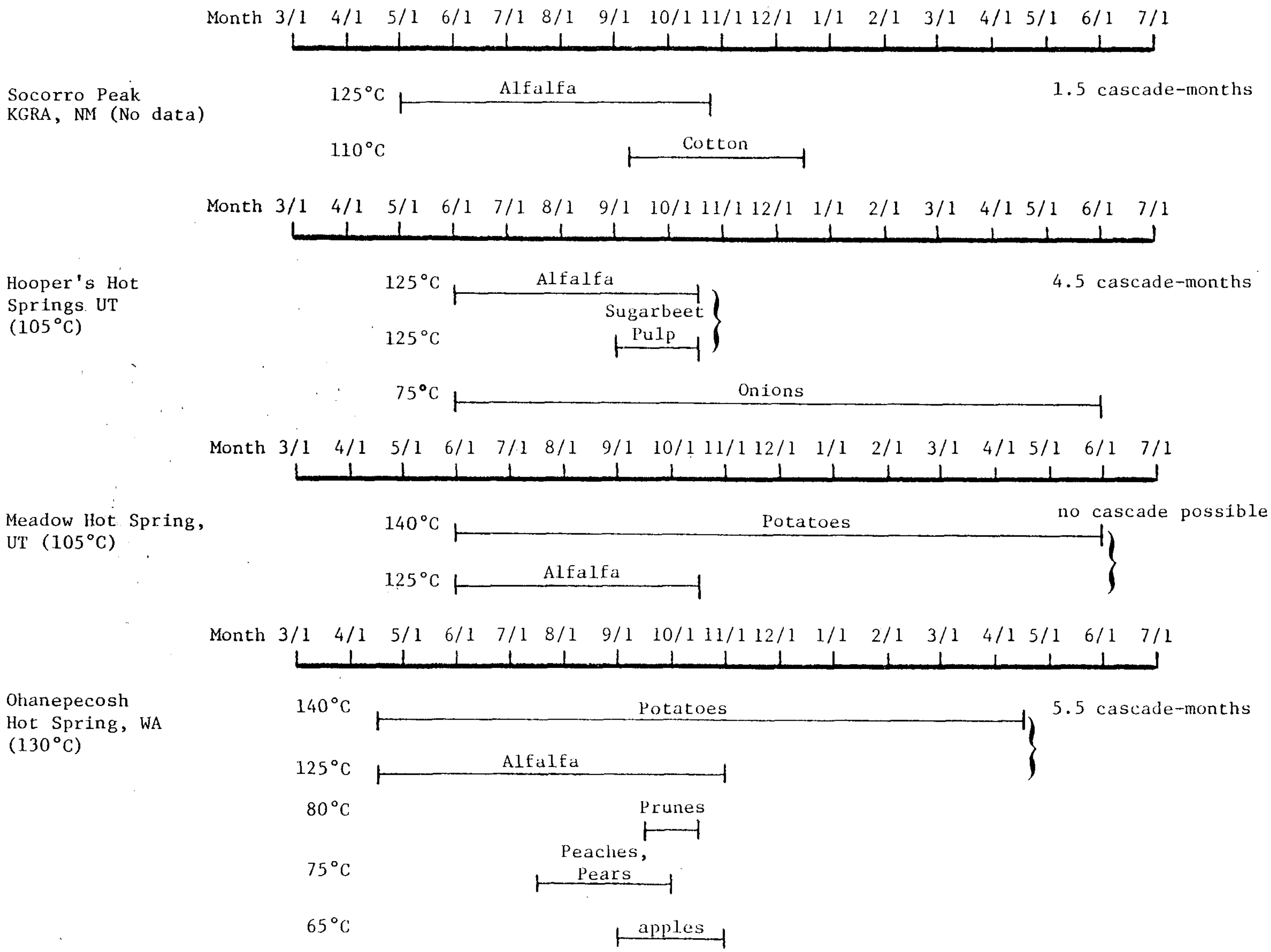

Figure D.3. (Continued)

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