CROP DRYING WITH GEOTHERMAL ENERGY

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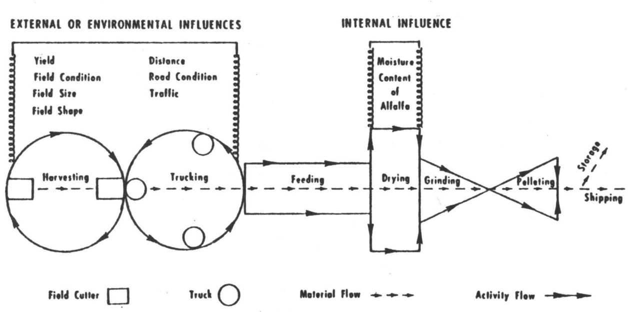
Alfalfa hay is one of the 10 most valuable crops in all 11 of the geothermally endowed continental states west of and including Montana, Colorado, and New Mexico. While most of the U.S. crop (about 70 x 10^6 tons annually) is sun dried for cattle, about 1.3 x 10^6 tons are dehydrated to preserve the nutrients in a product called "dehy." Dehy competes with other feedstuffs for inclusion in animal feeds and is desirable for its high protein content (17-22% by weight) and especially for the yellow xanthophyll that it contributes to poultry skins and egg yolks. While most of the 250 U.S. dehy plants are in the Midwest, in 1976 seven plants were operating in California and one in Idaho to supply poultry feeders; 16 Colorado and 2 New Mexico plants sold mainly to Texas feedlots.

Conventional dehydration (Fig. 1 and 2) is energy-intensive: 10^7 Btu's per dried ton are required to reduce the "green chop" from 75% (by weight) moisture to 10% dehy. Exposure of the green chop to intensely heated air and the products of natural gas combustion in a rotary drum dryer is the process universally used in the U.S. today. Green-chop residence time need be only 3-5 min with the usual 1000-1800°F air. Throughput is high for quite low dryer capital cost: a typical dryer at $130,000 (the Heil SD105-32, baseline for this study) produces 6800 dry lb/hr. (A dehy operation often has several drums to produce up to 35,000 tons/yr). The trade-off is obvious: dehydrators face gas curtailments and badly need alternative energy sources.



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

Fig. 1 Material and Activity Flow in Alfalfa Dehydrating Operations and Factors that Influence Rate of Flow with Equipment of Given Capacity

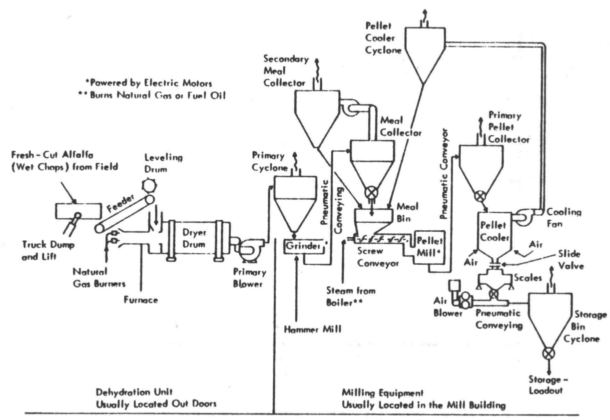


Fig. 2 Schematic of Alfalfa Dehydrating Plant

Might 90-150°C geothermal replace gas for dehydration? In general, one can modify existing dryers or introduce new ones; one can specify that geothermal supply all heat or only a portion. An obvious method would be a drum dryer with air in the 300°F range, a simple water-to-air heat exchanger replacing the furnace. A computer model was used to investigate drying at various temperatures and durations with a variety of dryer configurations. No combination was found that would allow viable rotary-drum dehydration with c. 300°F geothermal water. For example (Fig. 3), assuming initial and final moisture are 75% and 10%, retention time and thus drum length must increase dramatically as inlet temperature is decreased.

Two hybrids permitting geothermal to replace part of the natural gas were evaluated. An air preheater (Fig. 4) is the less costly. If the dryer system were 2 Heil SD105-32 drums with a combined capacity of 6 tons/hr dehy, about 11.5% of the required heat (6.6 x 10^6 Btu's/hr) could be geothermal. This assumes a fin-tube exchanger design with 781 lb/min tube-side (7050 ft^2) brine flow at 300°F inlet, 160°F return. Cost in 304 stainless (for Heber brines) is $105,700 (FOB), $212,000 installed.

A steam-tube dryer might "pre-dry" alfalfa from 75% to 60% prior to conventional dehydration to 10% (Fig. 5). Given use of the 2 Heil drums, minimum geothermal heat use would be 33%. Brine flow is 2792 lb/min at 300°F inlet and 160°F return, for 23.5 x 10^6 Btu's/hr. Assumed thermal efficiency of the steam-tube dryer is 75% eliminating 17.6 x 10^6 Btu's/hr of gas. Pre-dryer use may increase system throughput an additional 15-20% above 6 tons/hr. Cost for the steam-tube dryer with 304 ss tubes is $320,000 installed; additional materials-handling equipment is $51,400 (equipment only).

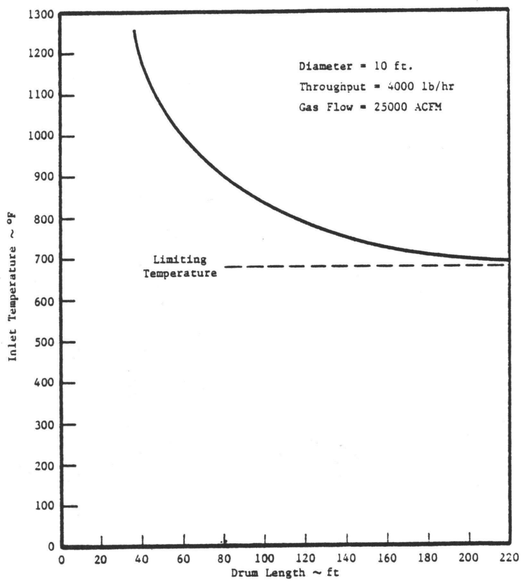


Fig. 3 Effect of Inlet Temperature on Drum Length

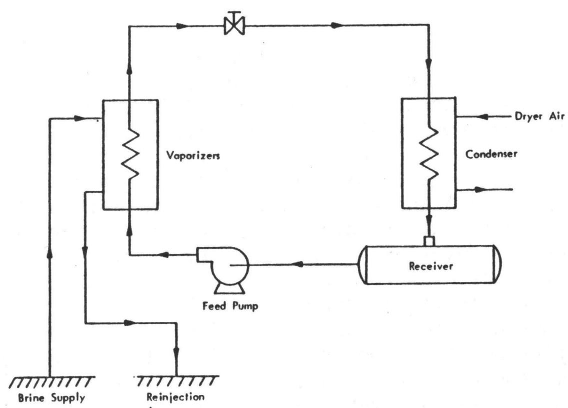


Fig. 4 Case 1: Geothermal Augmentation Design Using Simple Air Preheater

An all-geothermal alfalfa dryer is used by the 1 ton/hr dehy conveyor unit at the Broadlands, New Zealand. Flashed steam at 350°F, 150 psi is used in a coil to heat air to 200-290°F. Conveyors using fossil-fuel heat were used for alfalfa in the U.S. and still are in Europe. One such dryer, the Proctor Conveyor Dryer Model SCF was selected for analysis (Fig. 6); it now is used to dry animal feeds, onions, nuts, apples, carrots, etc. Conveyor belts may be woven-wire or perforated-plate designs; may run co- or countercurrent in one pass or many; feed and air flow are variable to dry different crops. Heated air is circulated at uniform velocity up or down through the drying material by turbine fans. With air recirculation, conveyor efficiency is only slightly lower than for the gas-fired drum; alfalfa residence of 30-45 min is required.

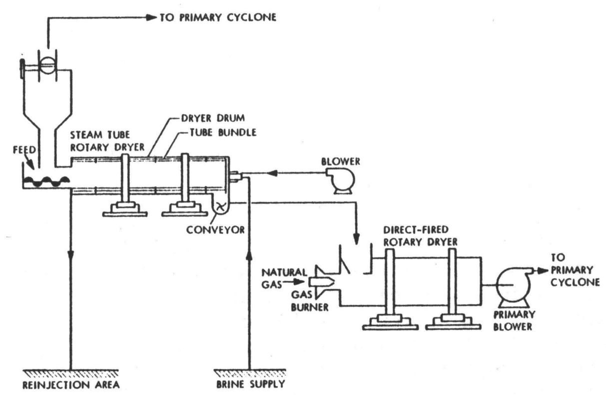


Fig. 5 Case 5: Steam-Tube Predryer Coupled to Gas-Fired Drum Dryer

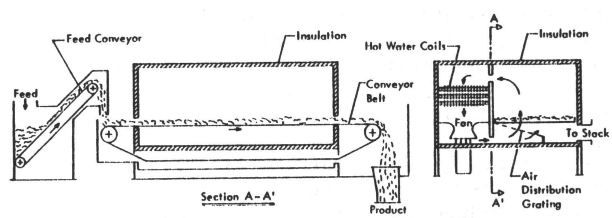


Fig. 6 Schematic of Proctor & Schwartz Conveyor with Geothermal Water Coils

Scale-up of the Broadlands design to 6 tons/hr dehy when brines like those of Heber are used requires alterations. Type 304 stainless, controlled fluid velocities, and provision for scale removal were included in our exchanger design. The decrease in fluid temperature from 350-300°F, our baseline, forces a minimum increase in heat-transfer area of 70%, assuming constant dryer size, inlet-air, dryer-air, and brine-return temperatures. Preliminary design calls for 2 parallel, redundant flow paths of three fin-tube units, each unit a bank of 1-in tubes 30 ft long. Total external surface for 300°F inlet, 160°F return brine flowing at 7714 lb/min; 20,040 lb/min air flow at 280°F dryer inlet, 160°F dryer outlet with recirculation, is estimated at 418,600 ft^2. Two dryers would be required for 6 ton/hr output; the length and width are each 98 ft and 12 ft with a drying area of 1100 ft^2 (Model SCF).

A preliminary estimate for retrofitting with these dryers is about $1.65m: $474,830 for the dryers, a like amount for installation; $348,000 for the exchangers, and the same for exchanger installation.

No cost savings were found for any of the designs: the additional cost per ton of dehy due to geothermal use was $2.50 for the preheater, $8.31 for the predryer, and $26.27 for the conveyor. The principal common assumptions were: 15-year loan at 10%; uniform brine cost of $\$2.50/10^6$ Btu's; 2¢/Kwh electricity; $\$1.50/10^6$ Btu's gas; taxes, insurance and G&A at 4% p.a. of added investment.

Annual dehy production has declined from a peak of 1.7×10^6 tons in 1970 due to California's loss of its Japanese market; gas curtailment; increased rural labor cost and decreased availability; and competition for land from other crops. This effectively bars most new plant construction and many have gone under. Thus potential geothermal use is effectively limited to retrofitting. Probably all 5 plants within 25 miles of USGS-identified hydrothermal systems (in Holtville, CA near E. Mesa KGRA; El Centro, CA: Heber KGRA; Twin Falls, ID: Cedar Hill area; 2 in Firebaugh, CA: Mercey Hot Springs) could finance a preheater or predryer, but the overriding threat of gas curtailment would remain.

The only dehydrator capable of financing an all-geothermal conveyor dryer is United Alfalfa Mills, El Centro (Fig. 7). UAM has unique advantages: it is large (4 drums for 12 tons/hr capacity); its market in Japan is relatively secure; climate and irrigation permit year-round operation; Valley Nitrogen Plant (VNP), a fertilizer factory considering geothermal, is next door. UAM was very interested in cooperating.

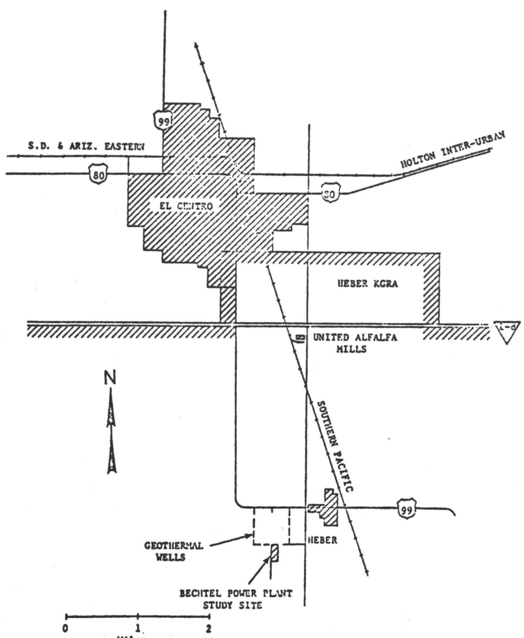


Fig. 7 El Centro Dehy Plant and Heber KGRA

The best scenario for retrofitting UAM with conveyor dryers (Table 1) involves 3.5 mi supply and 2.5 mi reinjection pipelines shared with VNP and sized for independent plant operation. Chevron Resources Co. estimated delivered energy price of Heber geothermal water to UAM alone; these figures were used to scale shared-pipeline estimates from the Battelle GEOCITY model to yield realistic delivered prices. Annual load factor for the shared transmission system (owned by Chevron; 15,429 lb/min brine at 300°F inlet, 160°F return) was 0.71; wellhead price, $\$1.84/10^6$ Btu's plus transmission cost, $\$0.74/10^6$ Btu's yields $2.58 delivered. Other operating and capital recovery costs were made site-specific following the format of the previous analysis. Total additional cost per ton dehy was $39.36 (40,000 tons/yr dehy output at 38% dryer load factor).

Table 1

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).

UAM felt this cost to be prohibitive. The probable course with energy prices in the $\$2$-$\$5/10^6$ Btu's range would be to halt dehy in favor of sun-cured production unless geothermal subsidy were made.

We found, in summary, that it is not cost-effective to retrofit current alfalfa-dehydrating plants or to construct new ones using moderate-temperature geothermal. We reached these conclusions because 1) there are few U.S. plants that are candidates for conversion; 2) conversion is costly and would add to the price of dehy an amount preventing competition with other feed ingredients; 3) construction of new plants cannot be justified on the basis of our economic/industrial/market evaluations; 4) even if geothermal use were encouraged through use of subsidies or other policy, the amount of gas to be saved is low; and 5) major gas curtailment would be damaging to the dehy industry. However, if such curtailment were to occur, geothermal would not be the best substitute since less expensive and energy-intensive alternatives to dehy are available.

What then is the prognosis for crop drying with geothermal heat? Many obstacles were found for alfalfa dehydration: much-increased capital cost in going to a lower-grade energy source; agricultural market instabilities and price competition with other feedstuffs allowing little "headroom" for added energy cost; a scarcity of plants near enough for retrofitting.

At least two options are available for alfalfa processing. Since substituting geothermal or even fuel oil for gas on a Btu-for-Btu basis probably will not be economical for dehy production, field-wilting alfalfa to 60% moisture prior to conventional drying may be the best short-term course. Appreciable energy could be saved throughout the U.S. (about 6 x 10^{12} Btu's if all dehy were wilted); dehydrators would save money; careful harvesting could prevent unacceptable nutrient loss. In the long run, sun-cured alfalfa and/or leaf-protein concentrate may supplant dehy.

Alfalfa retains unique potential advantages as a crop for geothermal applications, notwithstanding dehy production. Counties all or part of which are within 50 mi of geothermal resources (basis USGS Cir. 726 hydrothermal systems 90°C and above) in Table 2 grew 6% of 1969 U.S. alfalfa. Alfalfa can provide more protein per unit land (1500 lb/acre) than soybeans (580 lb/acre). This protein can be considered an underutilized resource with an energy barrier to efficient utilization. Wet-processing to produce leaf-protein concentrate (LPC) (Fig. 8) for both animals and humans is commercial in France and under intensive study at the USDA Western Regional Research Laboratory, where Dr. George Kohler predicts that white alfalfa LPC will be an important human food by 1990. Low to moderate temperature geothermal would be very appropriate in green-juice processing. Immediate energy savings could be had to the extent that LPC replaces dehy.

Other established crop-drying industries seem to offer better potential than dehy production for geothermal retrofitting. Estimates of drying energy used (Table 3) show that retrofitting of 5 industries--sugar beet pulp, potatoes, alfalfa, prunes, onions--could save 90% of 2 x 10^{13} Btu's/yr (drying heat only) used near geothermal by 12 industries studied; retrofit of all 12 could save 31% of their U.S. heat use. TRW's study (Report SAN/131703) concluded that rotary drum dryers might economically dry <u>sugar beet pulp</u> were geothermal brine first cascaded in sugar plants; drying is 30-50% fuel use. <u>Prune drying</u>, usually done in forced-draft tunnels at 165°F maximum, suits geothermal technically. Most U.S. dryers are in the Sacramento Valley; while all but one of the 15 largest are within 50 mi, they are typically at least 30 mi E or S of identified geothermal. Further study should determine: a) whether dryers could move to geothermal and retain their prune supplies; b) how to overcome the fact that dryers operate only 2 months/yr. <u>Onions</u> are usually dehydrated with multistage continuous-belt conveyors at 180°F maximum. The Vacaville (10-15 mi E of [Jacksons] Napa Soda Spring, 150°C subsurface) and Dos Palos plants (20 mi NE of Mercey Hot Springs, 125°C) might relocate to retrofit. All-year dehydration is usual so that a high utilization, dedicated geothermal system should be feasible.

Table 2

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)
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)

Potato dehydration to produce granules, flakes, slices, dices, and starch has excellent potential. Most of the various processes use 275° maximum air; flashed steam at 75-80 psi is conventional for flake and starch drying. Idaho's Snake River Valley contains at least 15 plants, only 2 more than 50 mi from identified geothermal; Colorado has 2 plants about 25 mi W of Alamosa County KGRA. Potatoes are dehydrated continuously; an average plant seems to run 280 days/yr, 24 hrs/day at 4 x 10^7 Btu's/hr to produce 25 x 10^6 lbs/yr at 80% utilization of plant capacity. Dedicated geothermal systems with short pipelines ought to be economical under such conditions; were all 16 plants less than 50 mi from identified resources retrofitted, about 4.2 x 10^{12} Btu's/yr fuel use could be eliminated.

A computerized crop data base was compiled containing, by county, the acreage, production, and dollar value within 50 mi of all Cir. 726 resources for 20 dryable crops (and 17 others, each of which was among the 10 most valuable crops in 1975 in at least 1 of the 11 geothermal states studied; some dryable crops satisfy this criterion). The 10 most valuable crops (Fig. 9) are worth 75% of the 37-crop total, \$1.7 x 10^9 (1969); these 10 include dryable alfalfa, potatoes, sugar beets, cotton, grapes, and rice. This data base might be used variously, e.g. for estimating the potential for geothermal irrigation or the impact of geothermal-associated pollution on crops.

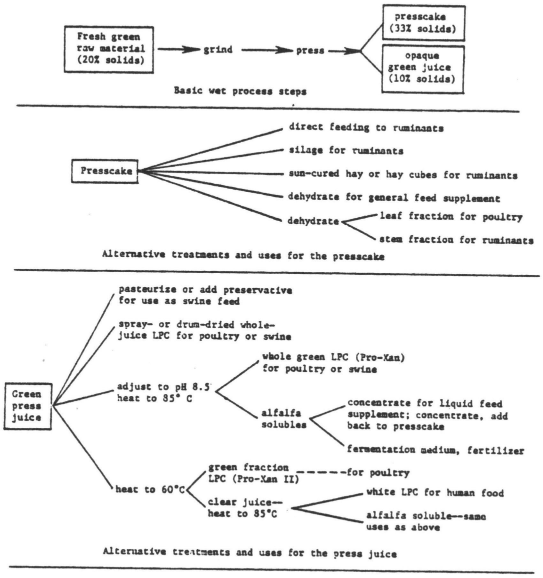


Fig. 8 Wet Processing of Alfalfa

Table 3

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%
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%

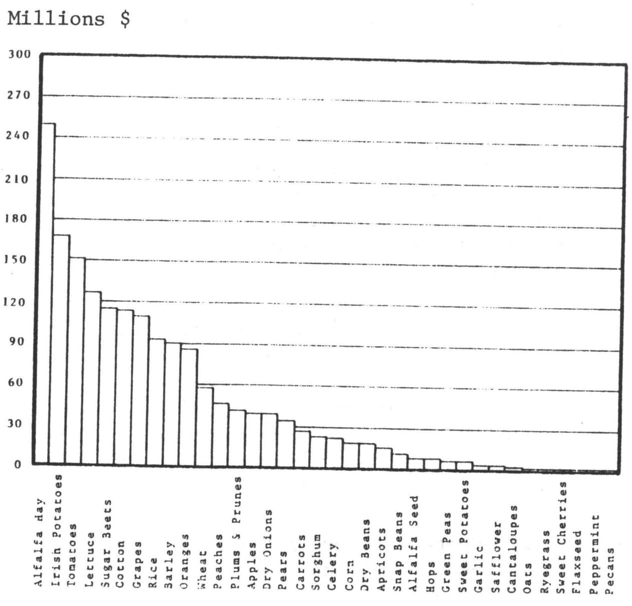


Fig. 9 1969 Continental U.S. Crop Values in Areas ≤50 Miles from Identified Hydrothermal Systems with Estimated Subsurface Temperatures Greater than 90°C.

The main use of this data base here was to select sites for conceptual multi-crop drying centers (MDCs) located at geothermal sites and operated most likely by cooperatives of companies from affected drying industries. To optimize geothermal use, potential MDC sites fulfilled several criteria. All are at resources that appear to be located on or very near (less than 2 mi) roads or railroads. All are in or near agricultural areas that grow 2 or more crops commercially dried at present in the U.S. Distance between MDC site and growing areas varied, but in no case was more than 50 mi. Finally, growing areas surrounding each MDC site had to produce amounts of the crops sufficient to warrant commercial drying.

MDC sites were grouped into high- (10 sites), medium- (15), and low-potential (13) groups with these criteria. Within each group sites were ranked with a figure of merit (FOM), a weighted composite of scores for several parameters: how adequate the resource temperature is vis-a-vis air temperature needed to dry the selected crops; length of drying season for the crop combination (assumed: the longer, the better capital is amortized); how efficiently brine might be cascaded from one component dryer to the next (Fig. 10); how many crops might be dried at the center (assumed: the more the better, all things equal). Finally, points were given when an MDC would demonstrate important means of reducing U.S. fossil-fuel use for crop drying.

A summary of the 10 MDCs with the highest figures of merit (Table 4) shows all have geothermal temperatures adequate to dry all proposed crops (for potatoes: 140°C brine [allows 5°C above maximum air temperature required for established process]; alfalfa: 125°C; sugarbeet pulp: 125°C;

cotton: 110°C; garlic: 90°C; prunes: 80°C; raisins: 80°C; onions: 75°C; carrots: 75°C; peaches, pears: 75°C; chilies: 70°C; apples: 65°C; rice: 60°C). A profile of a hypothetical "successful" MDC can be drawn: it is in California and operates year-round to process at least 2 crops. Alfalfa, onions, potatoes or cotton, and one other crop are dried. Raw materials are sufficient within economic distance of the center; markets for the dried products are readily accessible by road and/or rail.

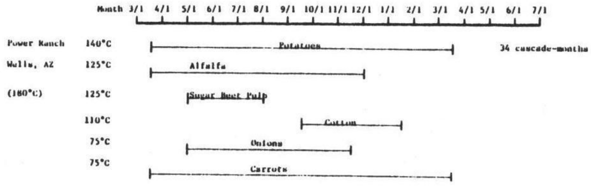


Fig. 10 Conceptual Drying Cascade: Power Ranch Wells, Arizona

Table 4

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.

Obviously, the process used to evaluate the MDCs provides comparison among the sites; absolute judgment of feasibility will require site-specific analyses: the intent of the foregoing is to provide a "shopping list" that may be useful to DOE policymakers and the crop-drying industry.

Work performed under the auspices of the U.S. Energy Research and Development Administration, Contract No. E(10-1)-1628.