SOLAR CROP DRYING DEMONSTRATIONS

Grant Number 01-5

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Acknowledgments

Many individuals contributed to the success of this project which actually consisted of five separate solar drying demonstrations spread over a four year period. Thanks to Bill Carrierre of Carriere and Sons, Mark Dalrymple of Sunsweet Dryers, Ron Keyawa of Keyawa Orchards Inc, Garry Vance of Korina Farms and Leslie Gardner of Sonoma County Herb Exchange for participating in the demonstrations and for their help throughout the installation and monitoring of their systems.

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Abstract

This project demonstrated the use of solar energy to dry crops grown in California using the low cost unglazed transpired solar collector displacing fossil fuels. The transpired collector or SOLARWALL system has been installed in over twenty countries primarily for heating commercial and industrial buildings. These demonstrations for the California Air Resources Board were the first applications of the transpired collector technology in the USA for drying of crops and it appears to have been the first significant improvement in solar drying technology since the 1980's.

The project involved site selection, design, installation and monitoring of five solar drying demonstration installations in California. Projects include drying of walnuts, pecans, prunes and herbs. All projects were successfully completed and are being used to dry their respective crops.

Introduction

This report is the final element of the ICAT grant to demonstrate solar crop drying in California. Solar drying uses solar energy to dry crops and displaces fossil fuels which are traditionally used for most drying applications.

The demonstration projects utilized a new unglazed solar air collector called a transpired solar collector, originally developed for space heating of buildings. According to the U.S. Department of Energy, "Transpired collectors provide the most reliable, best performing, and lowest cost solar heating for commercial and industrial buildings available on the market today." In 1992 DOE Inventions & Innovation Program rated the transpired collector invention in the top 2% of energy inventions. Prior to these demonstrations in California, the transpired solar collector or SOLARWALL panels had not been used in the USA for crop drying and in fact, very little, if any, new work had taken place in the area of solar drying since the mid 1980's.

Innovative Technology

The SOLARWALL collector is all metal, has no glazing and has no maintenance or moving parts. It is perforated and mounted out from a surface to create an air gap. Outside air is drawn through the perforations in the metal picking up the solar heat from the metal surface. *Figure 1* shows how it is mounted on the wall and *Figure 2* shows a picture of the panel. In these examples, the SOLARWALL panels are used to heat buildings and are wall mounted to better capture the low winter sun.

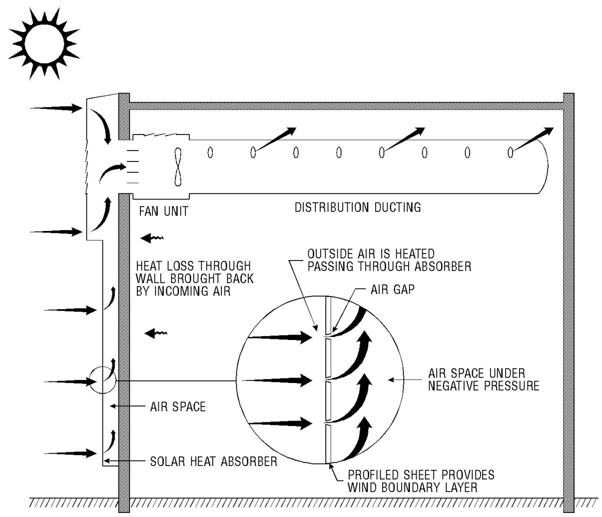

Figure 1: Cross section of SOLARWALL® panel connected to fan for heating buildings

Figure 2: Example of SOLARWALL® panel heating a military building

California is America's number one state for agricultural goods with annual sales in excess of twenty-six billion dollars. Many of these products such as onions, garlic, rice, grapes, prunes, nuts, fruit and seeds are dried and consume a tremendous amount of thermal energy in the drying processes.

As crop drying is normally done during the end of the growing season in summer and fall when the sun is higher in the sky, the panels can be roof mounted instead of wall mounted. The roofs also offered more surface area for collecting solar energy, displacing more fossil fuels. The roofs of drying buildings are not insulated and it was thought that for the roof mounted panels, additional heat would be collected from the warm air exiting the dryers and rising to the underside of the metal roof. *Figure 3* shows a typical roof mounted solar drying system.

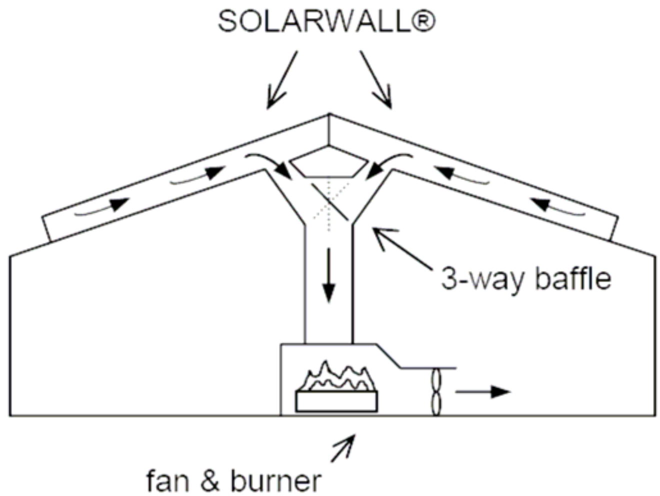

Figure 3: Typical roof mounted panels connected to a dryer

Solar crop drying was also new to the international scene and at the start of the ICAT project, the International Energy Agency Solar Heating and Cooling program formed Task 29 to demonstrate solar drying in various countries for a variety of crops. The California solar drying projects became part of this Task 29 representing the USA contribution to the program.

ICAT Project

The first stage of the ICAT project was to identify crops that could be dried, especially at lower temperatures, and then locate ideal sites for demonstrating solar drying technology on those crops.

The main technical goal was to demonstrate that solar energy using the transpired solar collector is a viable alternative or supplemental fuel for drying a wide range of crops in California. The transpired collector is able to raise ambient air temperature 20° to 60° F over ambient depending on air-flow and solar radiation levels. Many crops, such as rice, seeds, walnuts, and fish only require low temperature heat which is ideal for solar applications. Crops which need higher temperatures, such as onions and some fruits can still use solar as a preheater or companies can modify their operations to dry for a longer time at a lower temperature and switch to solar.

Most of the commercial drying operations visited or contacted for this project, burn natural gas or propane to heat the air in the drying operations. Most of the sites and prospective partners for demonstrating solar drying used a fossil fuel, and solar energy will reduce such fuel usage and the resultant pollutants that would have been produced. The only exception is the herb dryer which is 100% solar dried and uses no auxiliary fossil fuel.

One obstacle to overcome is the short drying time for many crops such as prunes. A solar heater is able to work 12 months a year displacing fossil fuels whenever it is in operation. Firms which have driers dedicated to only one crop, may operate them for only a few weeks a year. The low utilization factor affects the economics of solar, as well as the cost of having driers sitting idle for most of the year.

Original Work Plan

1. Identify suitable sites for solar drying and secure cost sharing contracts from owners

2. Visit each site, complete the final designs and installation drawings and fabricate the solar drying systems

3. Complete installations, commission each system and train operations personnel

4. Monitor the performance, collect and analyze the data during the drying season and prepare project data sheets on each installation

Crop Drying

Dryers usually need low grade heat to heat large volumes of air. This scenario is ideally suited for solar heating as low cost solar collectors can provide solar heat for large volumes of air. Solar panels can be added to the roof or walls of buildings housing existing dryers and the panels either heat or preheat the air entering the fan and dryer.

Each item to be dried can have its own special drying methods which can also vary from producer to producer. California has a wide variety of crops that require some form of heat for drying. Crops that were considered included:

- fruits such as prunes, apricots, pears, grapes (raisins);
- nuts such as walnuts, peanuts, almonds, pistachios and pecans;
- others such as rice, cotton, corn, seeds, spices, herbs, onions and garlic

Dryers can be a batch type or continuous. Batch dryers can have different configurations and continuous dryers also have various designs to move the products and introduce warm, dry air through them.

When solar heating is added to an existing dryer, the burner on the dryer must be capable of modulating the flame and turning off when sufficient solar heat is available. If the system has a modulating burner, then no changes should be needed to the existing dryer. Maximum savings occur when the auxiliary heater is turned off during the day.

The best candidates for solar drying are those that dry all year long as they have longer utilization of the equipment and thus have a quicker payback time to recover their investment.

Commercial dryers currently on the market have generally been designed for use with oil, gas, propane or steam as the heat source. Burning fuel produces higher temperatures than necessary and the actual dryer efficiency may be low since a lot of the heat is not utilized. The excess heat will leave the dryer and rise to the ceiling below the uninsulated metal roof. By mounting the solar panels on the roofs above the dryers, some of the lost heat can be recovered.

DEMONSTRATION SITES

As the ICAT project was a cost sharing project, each drying site required a financial contribution of at least 50% from the owner or other sources to cover their portion of the costs. Locating ideal sites with owners wishing to participate in a cost sharing demonstration of a new technology on a new application proved to be a greater challenge than originally anticipated.

The ICAT project called for five solar drying demonstration installations and five were selected and completed over the course of three years. The five systems represent a good cross section of applications and sizes ranging from 105 square feet in size to 9,300 square feet, low temperature to high temperature applications, short to long drying seasons, and new and retrofit locations.

Unstable energy prices, low food prices, competition from foreign producers and financial problems with some farmers and companies limited the number of people willing to participate in the program. Two of the initial companies submitting letters of intent did participate and three other companies were located after the program started. The five sites selected highlight an important factor: a crop with a high dollar value is better candidate for solar drying compared with a low value high volume crop with a short drying season.

Project # 1 Sunsweet Dryers – Prune Drying

Yuba City, CA
Contact person: Mark Dalrymple
Tel: 530-674-5010

SOLARWALL® size per dryer: 1,225 sq.ft.
Air volume preheated: 10,000 cfm of estimated 50,000 cfm total dryer airflow
Projected savings: 100 million BTU per month of operation per dryer per year
Maximum air temperature: 185° F

Prunes

California is the nation's largest producer of prunes and Sunsweet Dryers is the largest drying company in the prune business. The company currently operates 481 drying tunnels, each equipped with 3.2 MMBTU per hour burners.

Prunes are dried for approximately four or five weeks in late summer. Sunsweet has indicated an interest in using their dryers for other produce with solar energy, which would increase the utilization factor and significantly reduce the payback time. California has many companies which dry other fruit such as apricots, peaches, pears, cherries, etc. and these fruits are dried in tunnel dryers similar to the method for drying prunes. Most tunnel dryers burn natural gas, although some use propane and oil if gas is not available.

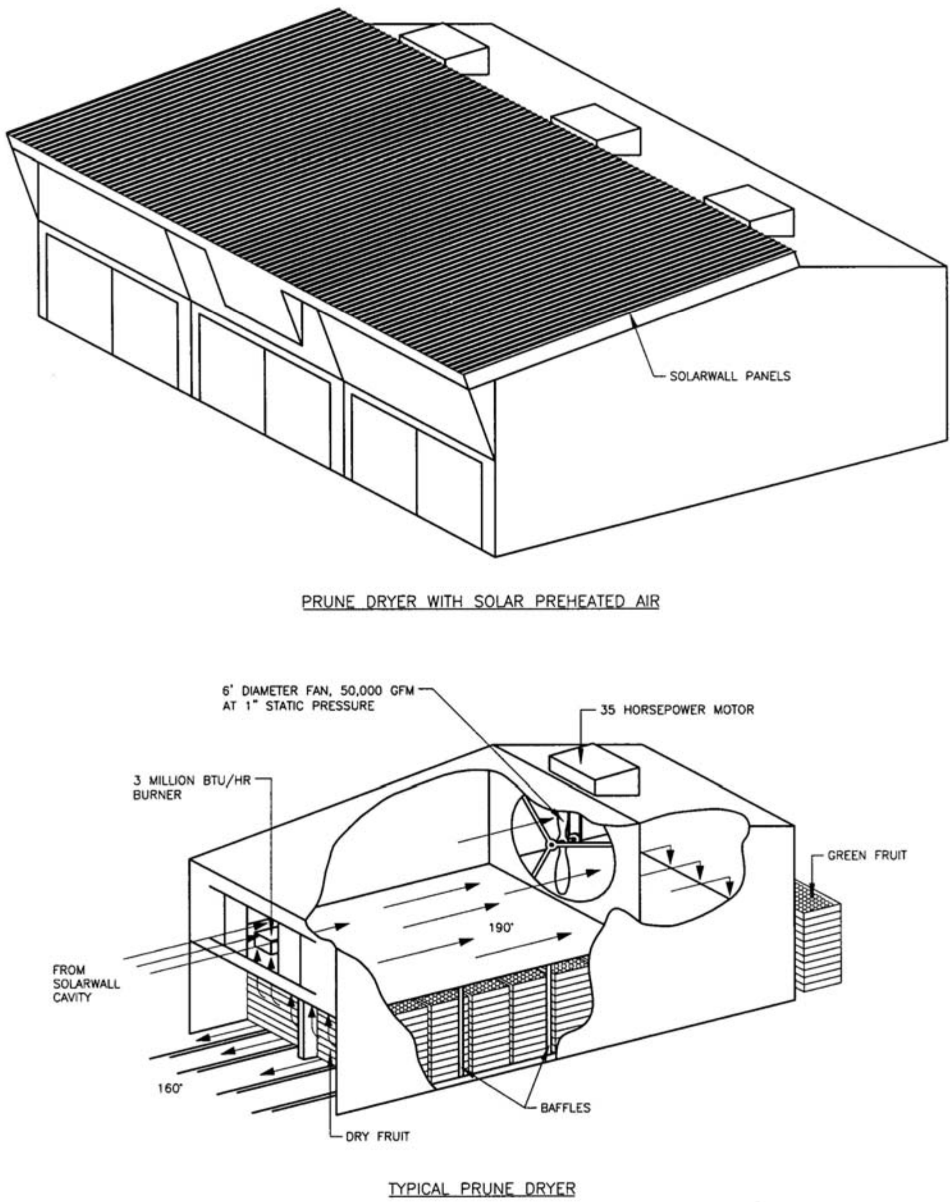

Figure 4: Typical prune dryer with roof mounted solar panels

Figure 5: Dryers with roof mounted SOLARWALL panels connected to air intake

Figure 6: Roof view with fruit racks outside dryers

Two demonstrations for drying walnuts were selected: the Carriere project as a typical size retrofit system and the Keyawa project as a large drying system on new construction. These are Projects #2 and #3 discussed next.

Project #2 Carriere and Sons – Walnut Drying
1424 Highway 45
Glenn, CA
Contact Person: Bill Carriere
Tel: 530-934-7454

SOLARWALL® size: 3,200 sq.ft.
Air volume heated: 17,500 cfm of 70,000 cfm total dryer capacity
Projected savings: 308 million BTU of natural gas for two and a half months drying
Maximum air temperature: 110° F

Walnuts
California is apparently the world's largest producer of walnuts with over 350 million dollars of sales annually. Walnuts are dried from an initial moisture content of 25% to a final moisture content of 9%. Typical drying temperatures are 110° F which is ideal for SOLARWALL. Drying period is approximately two and a half months from the end of August to early November. Fuel displaced is normally natural gas and in some cases, oil or propane.

Figure 7: Typical multi bin walnut dryer

Figure 8: Duct from solar panels on roof connect to walnut dryer

Figure 9: SOLARWALL panels on roof of dryer building

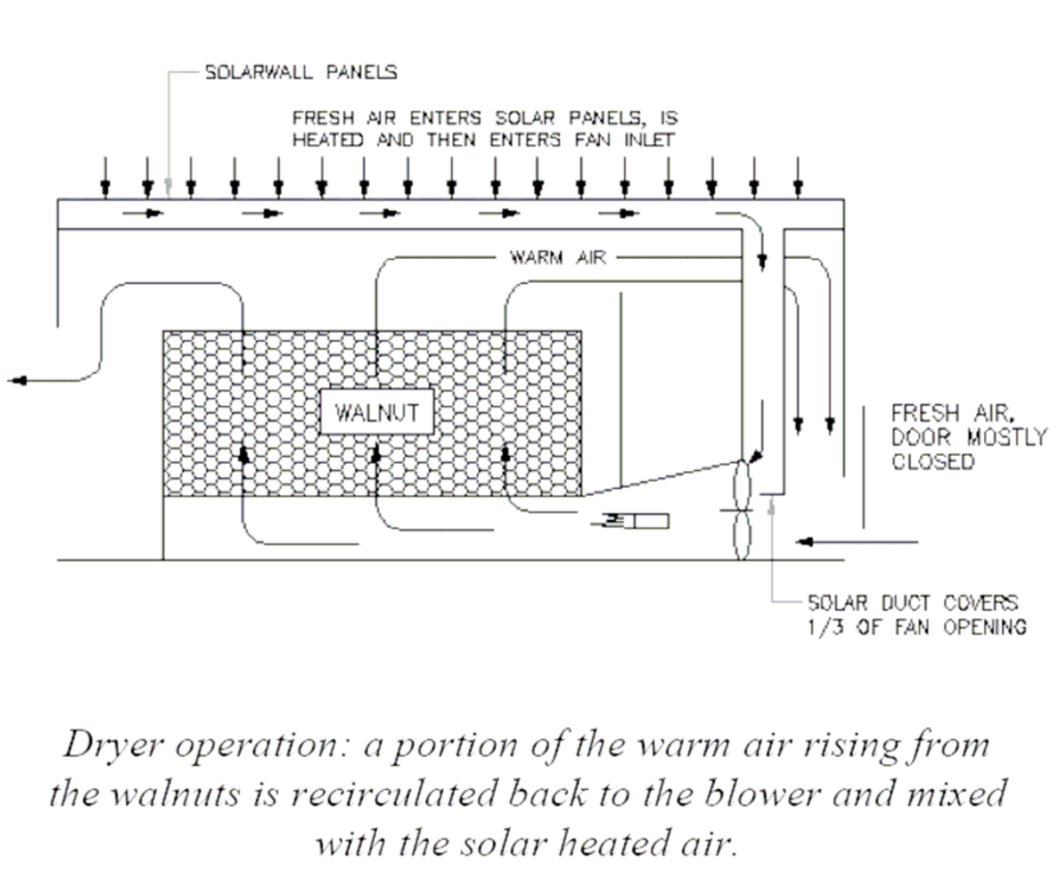

Figure 10: Typical walnut drying operation with solar heat, gas or propane heater, and ceiling heat recovery

Project #3 Keyawa Orchards Inc.
Chico, CA
Contact person: Ron Keyawa
Tel: 530-343-6972

SOLARWALL® size: 9,300 sq.ft.
Air volume heated: 65,000 cfm
Projected savings: 1,430 million BTU of natural gas for two and a half months drying

The Keyawa installation is the second of the two walnut dryers and is the largest solar drying project in California. It was incorporated into the new building during an expansion of the walnut drying operation.

Figure 11: Roof mounted panels, raised roof collection plenum & duct to dryer fan inlet

Figure 12: Solar ducts connected to two sides of 65,000 cfm dryer fan

Project #4 Korina Farms
Corning, CA
Contact person: Garry Vance
Tel: 530-824-3774

SOLARWALL® size: 5,200 sq.ft.
Dryer capacity: 30 tons per dryer, total of two dryers initially
Air volume heated: 37,000 cfm each for two dryers
Projected savings: 326 million BTU or 3,400 gallons of propane for two months drying

The Korina Farms pecan dryer is apparently the only dryer dedicated to pecans in the region and solar heating was incorporated into the new building. Pecans are dried after walnuts during the cooler and less sunny months of October and November. Pecan drying is a low temperature drying process and the maximum allowable air temperature is 80° F. The low temperature requirements and high air flow rates are ideal conditions for solar drying.

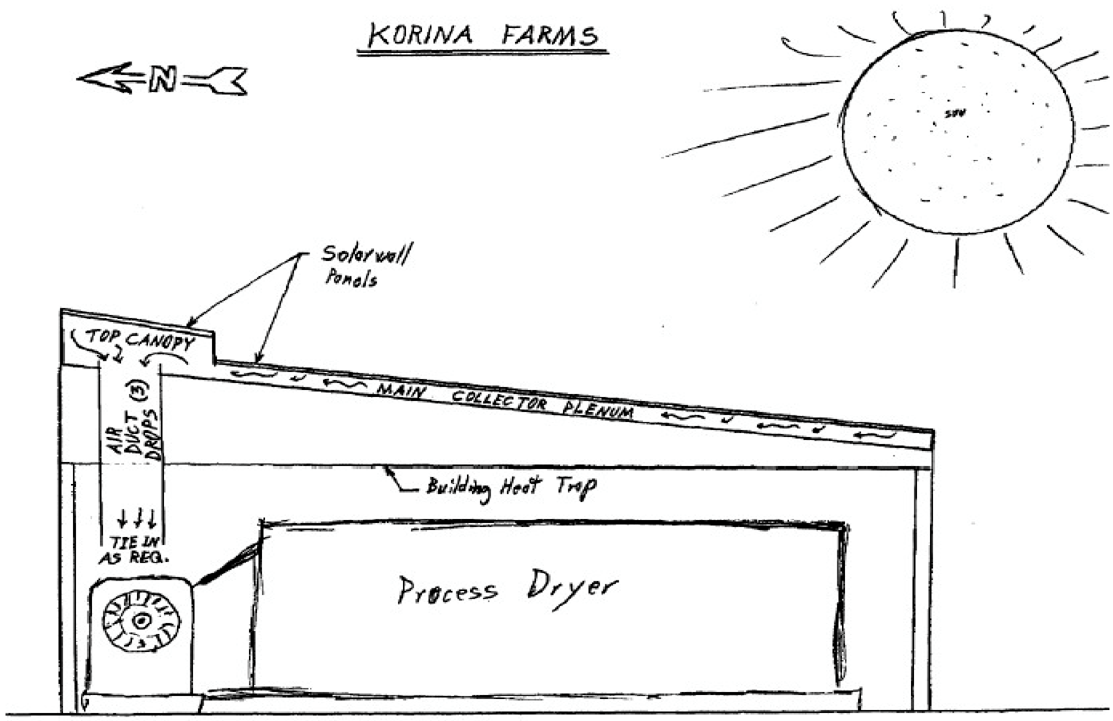

Figure 13: Schematic of pecan solar dryer

Figure 14: Pecan solar dryer with roof mounted solar panels, roof collection plenum and duct to one of two dryers.

Figure 15: Pecans

The sweet, mellow pecan is the fruit of a hickory tree and is the only major nut tree indigenous to the United States. The pecan nut is smooth and oval-shaped, with a thin, hard shell. Its rich kernel is golden brown on the outside and tan on the inside.

Project #5 Sonoma County Herb Exchange
Sebastopol, CA
Contact person: Leslie Gardner
Tel: 707-824-1447
SOLARWALL® size: 105 sq.ft.
Air volume heated: 350 cfm
Projected savings: 31 million BTU which would require 325 gal of propane for twelve months of operation

Figure 16: Batch herb dryer with sliding trays (doors closed when drying)

Figure 17: Solar panels on roof of office and dryer building

Project and Energy Costs

Total project costs shown in Table 1 below include all materials and labor for both the solar heating panels and the ducting to connect the panels to the intake of the dryers, but do not include any engineering, travel or monitoring costs. Costs do not include dryers as it is assumed that a dryer is available.

Each solar drying project was cost shared among three parties, California Air Resources Board, Conserval Systems Inc. and the respective demonstration partners. In addition, all projects qualified for the 10% commercial industrial solar energy federal tax credit. The total cost shown below would be typical of a similar project done on usual commercial terms. The net costs shown in Table 1 are the panel and installation costs for the dryer companies after taking into account the financial assistance from the various parties involved in the demonstration project.

Conserval provided the solar panels for free on the first two and last projects, the three smallest systems, in order to obtain commitments from the host parties to be the first to demonstrate solar drying on their particular crop. The panels for the two largest projects, Keyawa and Korina, were supplied by Conserval at a substantial cost reduction of approximately 35%.

The spot price of propane fluctuated wildly during the three years of the project starting at $1.10 a therm (100,000 BTU), then dropping to $0.45 and then back to the $1.00 range. Natural gas prices also varied but not to the same extent. Gas can be purchased on either a fixed contract price basis or on the current market price basis. For consistency reasons, we have elected to show energy costs at $1.00 a therm. The energy savings are highly dependant on the number of months of dryer usage. The longer the dryers are used the higher the energy and dollar savings will be.

The predicted energy savings are based on the simulations done by the program called SWIFT which was produced by Natural Resources Canada (http://www.canren.gc.ca/dtt/index.cfm?pid=3). The program is based on actual test data from earlier SOLARWALL installations. Appropriate weather data from the nearest weather station was used in each simulation. Solar drying can be considered as fuel switching from a fossil fuel to a renewable energy source.

Table 1: Summary of costs and savings

Project	**Total Cost $**	**Net Cost $**	**Energy Savings $/yr**	**# of months of Usage**
Carriere	32,000	6250	3500	2
Sunsweet	12,400	3000	1000	1
Keyawa	80,000	35,000	13,800	2.5
Korina	50,000	15,000	3200	2
Sonoma	4,000	500	350	9

All systems were installed and are currently operating or will operate when the drying season begins for the 2005 crop.

MONITORING

The projects were monitored during the months when drying occurred in 2004.

As Sunsweet has numerous dryers, a gas meter was installed on two dryers, the solar heated dryer and a conventional gas dryer, to be used as a base case. Sunsweet monitored gas consumption for the 2002 and 2004 seasons.

The monitoring of dryers for walnuts, pecans and herbs consisted primarily of temperature measurements of the ambient air and solar heated air for various times of the day. With this data and the fan capacity, the amount of solar energy delivered can be calculated. The herb dryer data is from 2005 as the dryer was not installed until after the end of the previous season.

The following summaries and graphs show the results of the monitoring program for 2004. The raw data are included in Appendix A.

Prune Drying

In an average year, Sunsweet burns approximately 4,800,000 therms of gas in their 481 dryers which equates to 10,000 therms per dryer. The temperature level in the tunnel dryers for prunes (and other fruits) is maintained at 185° F (85° C). Ambient air in July can range from low 70°'s to over 100° F which means that air must often be heated by over 100° F. The roofs of the dryers are not insulated and there is considerable amount of heat loss through the roofs. When SOLARWALL panels are mounted on the roof, much of the heat loss is recovered and returned to the dryer.

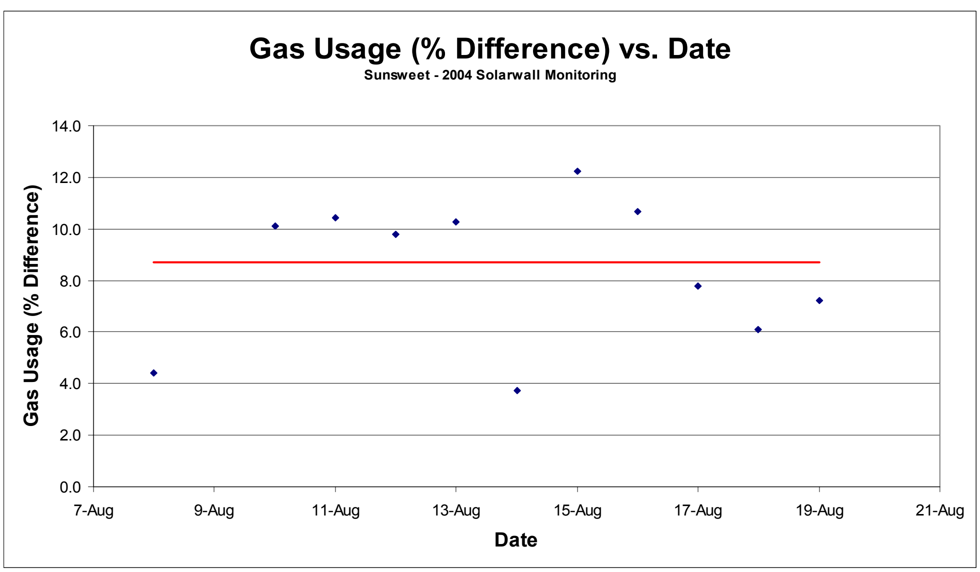

Figure 18: Prune drying – Average Solarwall Gas Savings: 8.7%

The solar panels provide preheating of the air to the prune dryer and the measured gas savings were 8.7% or 870 therms per dryer for a typical drying season. 2004 was not a typical season and in fact, it was the smallest crop in the history of the State with the shortest drying season ever with only 12 days of drying compared with 25 to 30 days for a typical year. Measured energy savings for the solar dryer in 2004 for the 10 days of actual measurement were 289 therms of gas or 28.9 therms per day average. (For comparison, a small California home might use 35 to 50 therms for an entire month of heating during a mild winter).

Table 2: Temperature Readings for solar prune drying

Date	Time	Ambient Temp. (°F)	Solarwall Temp. (°F)	Temp. Rise
08/12/04	13:30	109.4	129.4	20.0
08/13/04	15:30	104.3	126.6	22.3
08/14/04	13:00	96.4	127.4	31.0
08/15/04	7:15	75.7	99.8	24.1
08/15/04	8:15	98.9	121.6	22.7
08/16/04	11:15	80.4	127.6	47.2

Temperature readings for a few days show an average temperature rise from 20° F to 47° F. The wide range is due to amount of sunshine and position of the bypass dampers which are used to adjust the rate of moisture removal.

It becomes readily apparent that the longer the drying season, the higher the savings. One month of drying savings are approximately 900 therms and two months would be 1800 therms. If the prune dryer handled multiple fruits over many months, the savings would be even higher.

Walnut Drying

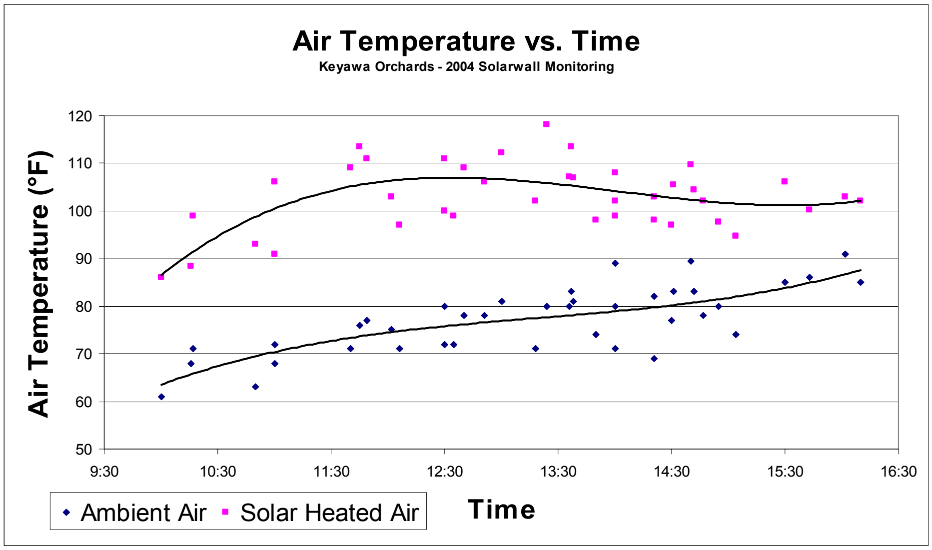

Figure 19: Walnut drying – average solar drying temperatures for sunny day in Sept & Oct.

The temperature readings in the previous graph were taken at Keyawa Orchards and have been averaged over the two drying months of September and October. The solar heating system was able to provide excellent results with delivered air temperature to the dryer at the 110° F range. The instantaneous heat output of the Keyawa installation is equivalent to a 500 kW (1,700,000 Btu/hr) heater. The energy delivered is approximately 17 therms per hour or approximately 150 therms per day time operation. Additional savings accrued during night operation with the heat loss recapture, but the operators at the site only recorded day time readings. It appears that the actual energy savings will be very close to the predicted savings of 1,430 million BTU/hr over 2.5 months of drying.

The Carriere walnut dryer produced similar temperature results, but on a system about one third the size (3,200 ft^2) and heating proportionally less air. The instantaneous heat output is equivalent to a 170 kW heater (580,000 Btu/hr). The actual temperature data that was provided for the Carriere project in 2004 was not accurate due to poor placement of the temperature sensors. By the time the problem was noticed, the drying season had ended.

Carriere was one of the first projects completed and it has been in operation since 2002. During 2002, Conserval representatives recorded temperature readings very similar to those measured at the Keyawa installation. After the 2002 season, Mr. Carriere reported total fuel savings of approximately 25% from the previous year, however, those numbers also included another dryer which was not solar heated so the actual savings from the solar dryer are likely higher.

Pecan Drying

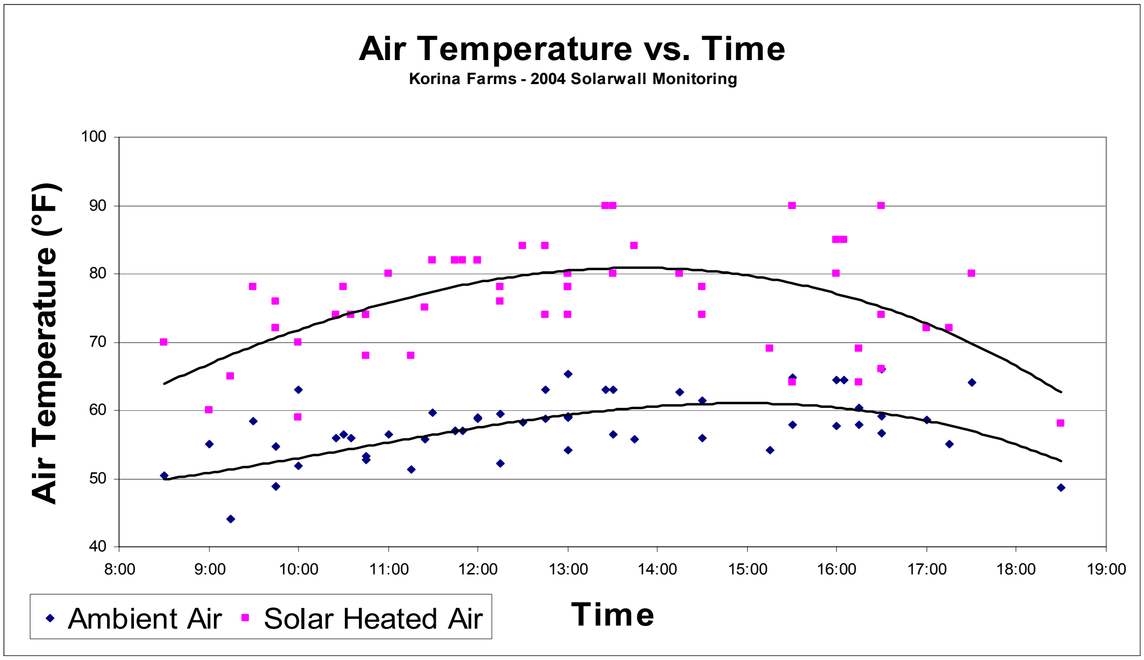

Figure 20: Pecan drying – average solar drying temperatures for sunny days in Oct & Nov

The temperature readings in *Figure 20* were taken at Korina Farms and have been averaged over the two drying months of October and November. The solar heating system was able to provide excellent results with delivered air temperature to the dryer at the 80° F range. The instantaneous heat output of the Korina installation is equivalent to a 265 kW heater (900,000 Btu/hr). The energy delivered on a typical sunny day is approximately 8 therms per hour or approximately 65 therms per day time operation.

The original savings estimate of 3,260 therms would be met with 50 sunny days of drying. The monitoring data was only taken over a four week period from Oct 23 to Nov 24. The heat recovery benefit seen in the walnut drying operation was not as significant at this installation. This may be due to the method of operation which was to dry as much as possible during the day and to bypass the solar panels during cloudy weather. On most sunny days, the propane burner was off for most of the day as can be seen from the data in the appendix.

Herb Drying

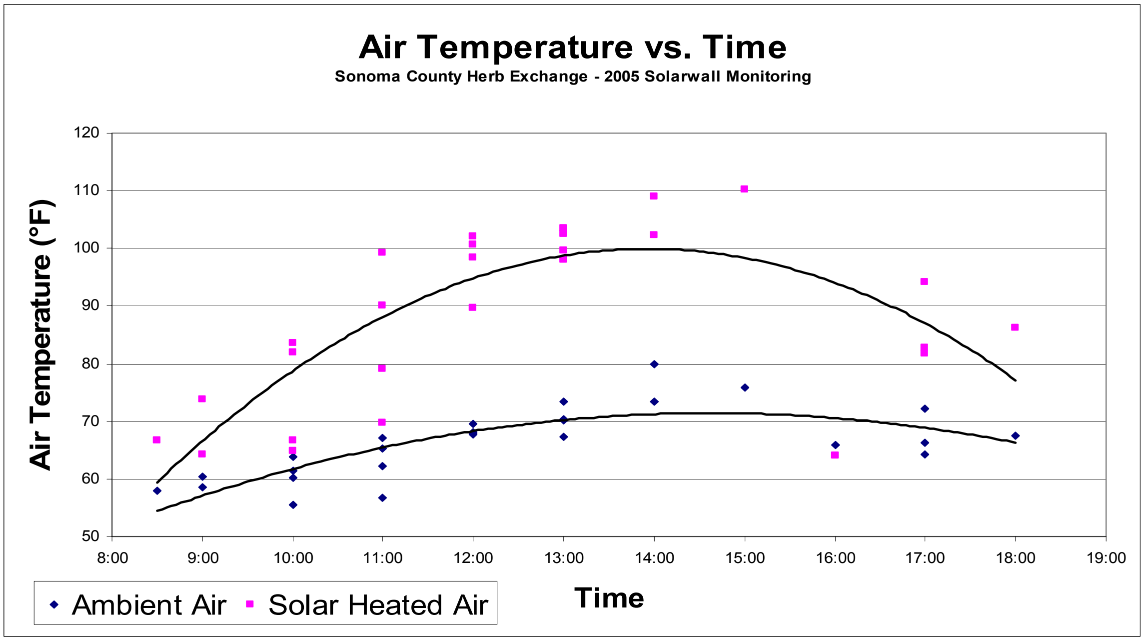

Figure 21: Temperatures from batch type dryer during April 2005

The temperature readings in *Figure 21* were taken at Sonoma County Herb Exchange and have been averaged over a few days in May 05. Previous readings in Sept to April showed similar solar temperature readings but the ambient temperature was only estimated and not sufficiently accurate. The solar heating system was able to provide excellent results with delivered air temperature to the dryer at the 80° to 110° F range. The instantaneous heat output of the Sonoma installation is equivalent to a 5 kW heater (17,000 Btu/hr). The energy delivered on a sunny day is approximately 0.25 therms per day time operation.

The savings are less than predicted and this is attributed to the measured air flow being 165 cfm which is less than half of the 400 cfm rating for the fan. An inspection of the duct connection between the roof and the dryer revealed the problem. The installer used flexible duct of 8” diameter instead of 10” diameter. The duct is longer than necessary which resulted in more turns and higher static pressure drop. The initial fan selection was for 1 inch H2O of pressure loss and this system has over 2 inches of pressure loss. Sonoma has been informed of the problem and once a larger duct is installed, the air flow should double, increasing the solar heat gain and thus the energy savings.

This system has no other heater except solar. Herbs are dried only on sunny days. The owners are very pleased with the system as it provides a new business opportunity for them and they can now offer dried herbs as well as fresh ones. As the solar panels are on the roof above the office, the owners plan to utilize the solar heat during the non drying season to heat their offices.

Emission Savings

Solar heating is non polluting and as it displaces fossil fuels, it also displaces the emissions associated with the fuels. Table 3 summarizes the reductions of the various gases with the largest savings being CO_2. The total CO_2 savings for the five projects is over 135 tons each year.

Table 3 Emission savings

	Sunsweet Prunes	Carriere Walnuts	Keyawa Walnuts	Korina Pecans	Sonoma Herbs
monthly fuel saved (MMBtu)	100	172	572	163	3
NOx (lbm)	6	10.32	34.32	9.78	0.18
CO (lbm)	19.76	33.9872	113.0272	32.2088	0.5928
SOx (lbm)	1.3	2.236	7.436	2.119	0.039
VOC (lbm)	2.6	4.472	14.872	4.238	0.078
PM10 (lbm)	1.2	2.064	6.864	1.956	0.036
CO_2 (lbm)	13900	24000	79700	22700	418
Months of use	1	2	2	2	9
CO_2 total (lbm)	13900	48000	159400	45400	3762

Conclusions

1. The five solar crop drying demonstration projects have been completed and all are operational and in use during the drying season for their respective crops. The projects selected range from one of the smallest systems of 105 square feet to the largest of 9300 square feet and include nut products, fruits and herbs. To the best of our knowledge, these new solar dryers are the first solar drying systems installed in California since the 1980's. The Innovative Clean Air Technologies program supports demonstration projects that can advance air pollution control and add to the State's economy. As these objectives have been met, the solar drying demonstrations can be considered a success.

2. The demonstration project took a year and a half longer to complete than expected due to the time needed to locate suitable demonstration sites and to wait for a complete drying season for the monitoring data. For future demonstrations, additional time should be allocated for the site selection and contract negotiations with the farmers and producers. Demonstrating a new technology or new application becomes interesting to farmers at a certain price level and it was necessary for Conserval to offer the first two projects at minimal cost to the owners. Once the first two were operating successfully, interest spread by word of

mouth to growers of similar crops which lead to the second and largest walnut drying installation.

3. The amount of energy consumed in the agricultural drying industry is significant but is also seasonal for many of the crops. The prune industry's largest supplier, for example, burns 4,800,000 therms of gas in less than one month of drying. Any solar drying equipment must be economical and designed for the short drying season. Consideration should be given to using dryers for multiple crops to extend the usage and increase the solar energy savings. The herb industry is an example of multiple usage as the solar dryer handles many herbs and medicinal plants and flowers. This dryer also provides additional income for the cooperative, which previously only sold fresh produce.

4. Other crops were considered and many sites visited but those sites were either not suitable or the owners were not interested in demonstrations. For example, rice drying has a very short season of a few weeks and large dryers, some outdoors and some with over 100,000 cfm capacity and no suitable surface area for mounting the panels. Cotton was considered but the problem with lint around many sites suggested that better demonstration sites could be found. The fruit industry is suffering from foreign competition and most producers were not interested in investing in new drying equipment. Seed drying was initially thought to be one of the most ideal applications with low temperature drying and ten or more months of drying. The seed industry is also suffering financially and no one was interested.

5. The producers most interested were those growing a high dollar value commodity such as the various nut products. Many walnut and pecan producers are expanding their operations and these and similar producers are interested in new technology to minimize their fuel usage and cost of operation. Two of the projects, Keyawa and Korina were on new drying buildings whereas the other projects were retrofits onto existing buildings.

6. The total solar panel area for the five projects is 19,030 square feet for an average size of 3806 square feet. Each square foot of transpired solar collector has a peak thermal output of 50 to 60 watts (170 - 200 Btu/hr.) of energy or 38 therms per hour for the five systems. The heat recovery from the lower roof side of the panels will contribute additional energy depending on the ceiling temperature and roof construction. The two walnut dryers and prune dryer were able to recover heat, especially during the night.

7. The following chart summarizes the energy savings.

	Sunsweet Prunes	Carriere Walnuts	Keyawa Walnuts	Korina Pecans	Sonoma Herbs
SOLARWALL Size (ft2)	1,225	3,200	9,300	5,200	105
Air Volume Heated (cfm)	10,000	17,500	65,000	37,000	350
Projected Savings (per month MMBtu)	100	172	572	163	3
Months of Use per year	1	2	2	2	12

Total Projected Savings (per month): 1,010 MMBTU
Total Cumulative Savings (per year): 1,950 MMBTU

8. Solar heating displaces fossil fuels and the emissions associated with those fuels. The total CO_2 savings for the five solar drying projects is over 135 tons each year.

9. Solar crop drying is still relatively unknown in the agricultural community. USA Department of Agriculture has a current RFP (March 28/05 – Renewable Energy Systems and energy Efficiency Improvements Grant Program) for farmers to use renewable energy on their farms but crop drying is not listed. USDA personnel, extension services and other agricultural program personnel need to be informed of the potential for solar drying, the success of the California demonstrations and the need to update data bases and manuals to include the latest solar crop drying methods and technology.

10. The ICAT program was instrumental in demonstrating solar crop drying in California and in the USA. Without the financial and moral support of the Air Resources Board, there would be no recent solar drying installations. Demonstrations such as these are essential to the introduction and commercialization of new technology and new applications.

Appendix A

Data Collected During System Operation

Project #1: Sunsweet Dryers (prunes)

	Gas Usage (ft^3)	
	Solarwall	Control
8-Aug	28967	30300
10-Aug	27148	30200
11-Aug	25970	29000
12-Aug	29684	32900
13-Aug	31041	34600
14-Aug	38033	39500
15-Aug	25981	29600
16-Aug	59045	66100
17-Aug	14939	16200
18-Aug	12396	13200
19-Aug	23570	25400
Total	316774	347000

8.7 % savings

	time	ambient T (°F)	solar T (°F)	delta T (F°)
08/12/04	13:30	109.4	129.4	20.0
08/13/05	15:30	104.3	126.6	22.3
08/14/06	13:00	96.4	127.4	31.0
08/15/07	7:15	75.7	99.8	24.1
08/15/08	8:15	98.9	121.6	22.7
08/16/09	11:15	80.4	127.6	47.2

Project #3: Keyawa Orchards Inc. (walnuts)

Date	Time	Ambient Temperature (°F)	Solar Temp (°F)	Mixed Air Temp (°F)	Recirc. Temp (°F)	Temp Rise (°F)
28-Sep	10:50	63	93.0	96.0	107.0	30.0
28-Sep	14:00	71	102.0	99.0	103.6	31.0
29-Sep	10:00	61	86.0			25.0
29-Sep	12:30	72	100.0			28.0
29-Sep	13:50	74	98.0			24.0
29-Sep	14:30	77	97.0			20.0
1-Oct	11:00	68	91.0	96.0	104.0	23.0
1-Oct	12:06	71	97.0	97.3	104.0	26.0
1-Oct	12:35	72	99.0	98.2	104.0	27.0
1-Oct	14:47	78	102.0	98.4	98.2	24.0
2-Oct	11:00	72	106.0	102.0		34.0
2-Oct	12:02	75	103.0	95.7	90.0	28.0
2-Oct	14:42	83	104.5	98.0	93.0	21.5
2-Oct	15:43	86	100.2	97.0	95.0	14.2
3-Oct	11:49	77	111.0	108.0		34.0
3-Oct	12:30	80	111.0	108.5		31.0
3-Oct	13:00	81	112.3	109.5		31.3
3-Oct	13:37	83	113.5	111.0		30.5
4-Oct	12:51	78	106.0	107.0	109.0	28.0
4-Oct	13:36	80	107.2	108.5	110.0	27.2
4-Oct	14:31	83	105.4	107.3	111.0	22.4
5-Oct	10:16	68	88.3	100.0	106.0	20.3
5-Oct	11:40	71	109.1	104.4	102.0	38.1
5-Oct	12:40	78	109.0	108.3		31.0
5-Oct	15:30	85	106.0	107.0	111.0	21.0
5-Oct	16:10	85	102.0	108.0	104.0	17.0
7-Oct	10:17	71	99.0	98.0	106.0	28.0
7-Oct	11:45	76	113.5	98.2	109.8	37.5
7-Oct	13:24	80	118.2	104.0	105.3	38.2
7-Oct	13:38	81	107.0	104.0		26.0
7-Oct	14:21	82	103.0	101.3		21.0
8-Oct	14:00	80	99.0	103.0	1083.0	19.0
9-Oct	14:21	69	98.0	105.0	112.0	29.0
9-Oct	13:18	71	102.0	103.0	110.0	31.0
9-Oct	15:04	74	94.8	91.4	88.5	20.8
10-Oct	14:55	80	97.7	95.5		17.7
12-Oct	14:00	89	108.0	97.7	87.6	19.0
12-Oct	14:40	89.5	109.6	101.3	94.6	20.1
12-Oct	16:02	91	103.0	100.4	98.6	12.0
					Average	25.81538

Project #4: Korina Farms (pecans)

date	time	ambient	solar temp	recirc temp	mixed air	weather	solar dmpr	amb dmpr	dryer loc
10/23	9:30	55.6	58.0	57.2	55	lt rain	open	clsd	e3-4
10/23	10:30	54.7	58.0	56.5	70	same	same	same	same
10/23	12:00	56.5	60.0	56.8	80	same	same	same	same
10/23	14:00	58.1	60.0	58.6	80	hvy rain	same	same	same
10/23	15:30	58.6	62.0	59.0	80	cldy	same	same	same
10/23	16:30	59.2	66.0	59.2	80	cldy	same	same	same
10/23	18:30	59.6	60.0	59.6	80	dark	same	same	same
10/23		58.1	58.0	58.1	80	dark	same	same	same
10/24		54.1	54.0	55.9	80	lt clds/sun	same	same	same
10/24	9:00	55.0	60.0	57.2	80	mstly sun	same	same	same
10/24	10:25	56.0	74.0	66.7	84	sun	same	same	same
10/24	10:35	56.0	74.0	66.7	74	sun	same	same	same
10/24	12:00	58.8	82.0	66.6	82	sun	same	same	same
10/24	13:25	63.0	90.0	66.6	90	sun	same	same	same
10/24	13:30	63.0	90.0	66.6	85	sun	50.00%	50%	same
10/24	16:30	66.0	90.0	66.6	85	sun	same	same	same
10/24	17:30	64.0	80.0	65.4	80	sun	open	clsd	same
10/24	18:30	59.0	62.0	59.6	62	sunset	same	same	off
10/25	8:00	52.0	52.0	52.0	75	rain	clsd	open	e 3-4
10/26	13:00	54.2	74.0	54.6	74	ptly cldy	open	clsd	e 2-6
10/26	14:30	55.9	78.0	58.5	78	ptly cldy	same	same	same
10/26	16:15	57.8	64.0	58.8	85	cldy	same	same	same
10/26	22:00								off
10/27	11:15	51.3	68.0	52.7	68	sun	open	clsd	e 3-6
10/27	12:15	52.3	76.0	55.2	76	sun	open	clsd	same
10/27	13:45	55.8	84.0	59.5	84	sun	open	clsd	same
10/27	16:00	57.7	80.0	62.1	80	sun	open	clsd	same
10/27	16:30	56.7	74.0	61.2	74	sun	open	clsd	same
10/27	17:15	55.0	72.0	59.7	72	sunset	open	clsd	off
10/28	15:30	64.8	90.0	68.0	85	sun	50%	50%	e3-4
10/28	16:00	64.4	85.0	68.4	80	sun	50%	50%	same
10/28	16:05	64.4	85.0	68.4	85	sun	open	clsd	same
10/28	18:30	48.7	58.0	62.0	58	dark	open	clsd	off
10/30	11:00	56.5	80.0	62.0	80	sun	open	clsd	e1-5
10/30	12:30	58.2	84.0	62.0	84	sun	open	clsd	same
10/30	12:45	58.8	84.0	62.5	76	sun	clsd	open	same
10/30	13:30	59.4	100.0	63.1	76	sun	clsd	open	same

Project #4: Korina Farms (pecans) continued

date	time	ambient	solar temp	recirc temp	mixed air	weather	solar dmpr	amb dmpr	dryer loc
10/31	8:30	50.5	70.0	55.8	85	sun	open	clsd	same
10/31	9:45	54.7	76.0	59.0	89	sun	open	clsd	same
10/31	10:30	56.5	78.0	60.4	92	sun	open	clsd	same
10/31	12:00	59.0	82.0	63.7	82	sun	open	clsd	same
10/31	14:15	62.6	80.0	65.5	80	sun	open	clsd	same
10/31	16:15	60.4	69.0	64.0	69	sun	open	clsd	off
11/4	13:30	56.5	80.0	58.1	80	sun	open	clsd	e1-6
11/4	15:15	54.1	69.0	59.4	69	sun	open	clsd	same
11/8	10:00	51.8	59.0	53.1	59	high fog	open	clsd	e 1-6
11/8	10:45	53.2	68.0	55.6	68	ptly sunny	open	clsd	same
11/8	11:25	55.8	75.0	57.2	75	same	open	clsd	same
11/8	12:15	59.5	78.0	59.9	78	same	open	clsd	same
11/8	14:30	61.5	74.0	60.8	74	mstly cldy	open	clsd	same
11/8	17:00	58.5	72.0		80	sunset	open	clsd	same
11/9		55.0			80	cldy	open	clsd	same
11/9	13:00	65.3	80.0	63.0	80	cldy	open	clsd	same
11/18	10:30	54.5	54.0	55.2	54	fog	clsd	open	e1-5
11/18	12:00	55.0	55.0	59.0	80	fog	clsd	open	same
11/19	8:00	58.2	60.0	59.2	80	sun	open	clsd	same
11/19	10:00	63.0	70.0	63.1	68	sun	open	clsd	same
11/19	12:45	63.0	74.0	63.1	80	sunny	open	clsd	same
11/22	9:30	58.4	78.0	60.8	94	sunny	open	clsd	w 1-6
11/22	11:30	59.7	82.0	59.7	80	sun	open	clsd	same
11/22	13:00	59.2	80.0	59.6	78	sun	open	clsd	same
11/23	15:30	57.9	64.0	58.1	80	hgh clds	open	clsd	same
11/24	9:15	44.1	65.0	54.0	88	sunny	open	clsd	w 1-6
11/24	9:15	44.1	65.0	54.0	65	sunny	clsd	open	e 1
11/24	9:45	48.9	72.0	59.4	88	sun	open	clsd	w 1-6
11/24	9:45	48.9	72.0	59.4	66	sun	clsd	open	e 1-2
11/24	10:45	52.7	74.0	62.3	72	sun	open	clsd	w 1-6
11/24	10:45	52.7	74.0	62.3	66	sun	clsd	open	e 1-2
11/24	11:45	57.0	82.0	63.0	78	sun	open	clsd	w 1-6
11/24	11:45	57.0	82.0	63.0	70	sun	clsd	open	e1-3
11/24	11:50	57.0	82.0	63.0	78	sun	open	clsd	e1-3
11/24	13:00	59.0	78.0	65.0	74	sun	open	clsd	w1-6
11/24	13:00	59.0	78.0	65.0	74	sun	open	clsd	e1-3

Project #5: Sonoma County Herb Exchange (various herbs)

Date	Time	Ambient Temp (°F)	Solar Temp (°F)
30-Apr-05	8:30	57.9	66.6
	9:00	60.3	73.8
	10:00	63.9	83.5
	11:00	67.1	99.3
	12:00	69.6	100.6
	13:00	70.3	102.4
	17:00	72.1	94.1
	18:00	67.5	86.3
02-May-05	9:00	58.5	64.3
	10:00	61.3	82.0
	11:00	65.2	90.0
	12:00	68.1	98.5
	13:00	70.2	103.5
	14:00	73.3	109.1
	15:00	75.9	110.2
	17:00	66.2	82.8
03-May-05	10:00	60.1	66.7
	11:00	62.3	69.7
	12:00	67.7	89.6
	13:00	73.5	99.6
	14:00	80.0	102.3
04-May-05	10:00	55.5	64.9
	11:00	56.7	79.1
	12:00	68.0	102.1
	13:00	67.3	98.0
	16:00	65.8	64.0
	17:00	64.2	81.7

Appendix B

Emission Reductions

*Emission Factors from SJVAPCD**

NOx	0.06	lbm/MMBtu
CO	0.1976	lbm/MMBtu
SOx	0.013	lbm/MMBtu
VOC	0.026	lbm/MMBtu
PM10	0.012	lbm/MMBtu

*San Joaquin Valley Unified Air Pollution Control District Memorandum "*Emission Factors for Calculations of Emissions from Natural Gas Burners Used in Agricultural Products Dehydration Operations*", revised June 29, 1998

CO2 emission factor calculation

1	therm =	100000	Btu =	100	scf
1	mole CH_4	produces	1	mole CO_2	
16	lbm CH_4	produces	44	lbm CO_2	
p =	14.7	lbf/in^2			
T =	68	deg F			
R =	79.1	ft-lbf/lbm-R			
rho=p/RT=	0.050684	lbm/scf			
CO_2	139.3805	lbm/MMBtu			

	Sunsweet	Carriere	Keyawa	Korina	Sonoma
	Prunes	Walnuts	Walnuts	Pecans	Herbs
monthly fuel saved (MMBtu)	100	172	572	163	3
NOx (lbm)	6	10.32	34.32	9.78	0.18
CO (lbm)	19.76	33.9872	113.0272	32.2088	0.5928
SOx (lbm)	1.3	2.236	7.436	2.119	0.039
VOC (lbm)	2.6	4.472	14.872	4.238	0.078
PM10 (lbm)	1.2	2.064	6.864	1.956	0.036
CO_2 (lbm)	13900	24000	79700	22700	418
Months of use	1	2	2	2	9
CO_2 total (lbm)	13900	48000	159400	45400	3762