Energy Analysis of Walnut Production in California

ABT 289A Final Report

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Abstract

The United States is the third largest walnut producer in the world (FAO, 2015), and California is the largest producer in the United States (Ferrira, 2017). Many steps taken during walnut processing are energy intensive, including harvesting, drying, processing, and transportation. Therefore, the purpose of this project is to identify and categorize areas of energy consumption during walnut processing in California. Because energy estimates have not been updated since 2009, there is a need to re-evaluate current practices. By understanding the energetic costs of each step, walnut-processing methods can be improved. Drying data collected from drying facilities in northern California were compared to similarly collected data from 2009 and 1980. Data related to the other steps (harvesting, processing and transportation) in walnut processing were evaluated using published work. Currently, the walnut industry uses 13 MJ per kilogram of walnuts produced, essentially unchanged from the values obtained for 2009. In 1980, 39 MJ were used per kilogram produced. Hence, there has been a 60% drop in energy consumption from 1980, which is largely attributable to the decrease in energy use in the drying step. Nevertheless, drying still accounts for a sizable fraction of the energy use in production at 10%. The largest contributor to total energy is transportation at 59%, due to the localized production of walnuts in California. As environmental concerns become increasingly prominent, it is important to keep food systems updated, and it is apparent that processing in the walnut industry has room for optimization. A particular step that can be targeted for improvement is the process of dehydration. In addition to the potential for conserving energy, this step dictates the walnut's eventual quality and wholesale value to a large degree, since moisture content determines the sale weight as well as the likelihood of becoming rancid.

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Introduction

In the United States' agriculture sector, 1.7 quadrillion BTUs of energy are consumed annually. The United States Department of Agriculture has estimated that 31% of edible food was wasted in the United States (USDA, 2017; Cuellar, 2010). This estimation includes food losses in the following steps; agriculture, transportation, processing, food sales, storage and preparation. 16% of tree nuts and peanuts were wasted according to the estimations of Kantor et al. (Kantor and Lipton, 1997). These statistics demonstrate the need to re-evaluate current processing systems to reduce food loss and energy use. The United States is responsible for 12% of the world's walnut production and it is the third biggest walnut producer in the world (607,810 metric tons), according to the Food and Agricultural Organization of the United Nations in 2016 (FAO, 2016). Therefore, walnuts are a major specialty crop in the United States, producing over $1 billion dollars in revenue annually (Perez, 2017). Having a large volume of production in United States and high food loss in the nut industry make walnut production steps worth investigation to minimize energy use.

The walnut was first planted in California in late 1700, and due to the state's Mediterranean climate, a tremendous increase in walnut cultivation has been observed since then. In the late 1800s, commercial plantings began and California has advanced in walnut production (Elkins, Klonsky, and Tumber, 2012). In 2016, California produced ninety-nine percent of the walnuts in United States (Parsons, 2017). Thus any energy and cost analysis of the walnut industry made in California should reflect the whole United States walnut industry and a significant portion of the world. As discussed in the previous paragraph, energy consumption in agricultural sector is intensive. Therefore, it is important to identify and categorize the energy consumption in walnut production and any crop production to make any improvements.

Walnut production can be categorized into planting, cultivation, harvesting and post-harvesting. Walnuts can be harvested approximately four to five years after planting (Elkins et al.,2012). Even in a well-established walnut orchard approximately 5% of the trees are replanted annually. Fertilization, pruning, irrigation and pest control are the major cultural costs. The walnut harvest season in California starts in September and goes until December. Harvesting is mostly mechanized in the United States. Therefore, harvest costs do not contribute significantly to overall walnut production cost. Once the walnuts are collected, the outer hull of the walnuts are removed. After the hulling step, the walnuts are dried. USDA standards impose certain regulations for dried walnuts such as about their moisture content, color and shell strength (Elkins et al., 2012). Most of these properties are controlled in the post-harvest drying step. It is important to understand and optimize the drying process to prevent walnut rejection in the commercial market. Walnuts are most commonly dried in stationary bin dryers by flowing hot air. The drying process utilizes fuel (usually propane or natural gas) to supply heat to the system and electricity for blowing air and operation (Thompson, 1997). Walnuts are also sold by dry weight; therefore, over drying should be prevented to maximize revenue. Hulling and drying are usually performed at off-site processors (Elkins et al., 2012). Transport from the orchard to these processors brings additional cost. After drying step walnuts can be further processed and packaged to be sold in the market (Elkins et al., 2012).

The goal of this project is to identify and categorize the energy consumption of post-harvest walnut processing with a special emphasis on the drying process. Our client is Dr. Irwin Donis-Gonzalez, who is a postharvest specialist in University of California Cooperative Extension. One of his current projects is in partnership with the California Walnut Board. There have not been any studies that examined energy consumption in the post-harvest processes of walnuts nearly in last eight years. Dr. Gonzalez needs this energy analysis to demonstrate that there is an opportunity in the drying step for researchers to reduce the energy use and improve the quality of the product. His research on the drying mechanisms of walnuts could also potentially increase the revenue in walnut production through increased quality and greater weight by avoiding over-drying. He believes that saving even a few megajoules of energy during walnut production can have a substantial effect on the environmental and economic sustainability of the walnut industry. Eventually the result of this project will set the fundamentals for future projects that our client is hoping to take on.

Figure 1: *Life cycle of walnut production in the United States.*

Literature Review and Prior Work

Walnut Processing in the United States

In the United States, walnuts are processed in six major steps (Figure 1). They are first produced and harvested from the field. This step involves the use of human labor, machinery, fuel and transportation; it can also involve fertilizers and pesticides. Post-harvest processing is the second step in walnut production. This step involves hulling and dehydration of the walnut. The green husk of the walnut is removed with an automated huller; the walnut can be sorted from the broken husk manually or electronically. In the third step, the walnuts are dehydrated in-shell until an average moisture content of 4.3 % wet basis (w.b.) of the shelled nut is achieved (USDAa, 2012). The walnuts are then transported to processing facilities where they are shelled, roasted, packaged, and stored at low temperature in the fourth step. The extent of the processing at this step depends on the final product. The walnuts are then transported to retailers in the fifth step. In the sixth and final step, the consumer processes the walnuts before consumption.

In this analysis, transportation across all six steps will be combined for ease of calculation. The digestion of the product and the recycling of the walnut shells, food loss, and food waste will not be included in the analysis. Although the energy associated with these by-products are often used for biomass and compost, the downstream use of these by-products is not within the scope of this project.

Production Levels in the United States

From all USDA reports, all production within the United States comes from California (see Figure 2). It was estimated in the 2017 Fruits and Tree Nuts Outlook that the United States will produce over 600,000 metric tons of walnuts (in-shell basis) in the 2016/2017 growing season (Ferreira, 2017). This would be a nine percent increase from the 550,000 metric tons sold in 2015. In 2013, domestic walnuts were being sold at an average market price of $3,710 per ton. In 2014, prices dropped ten percent and walnuts were being sold for $3340 per ton. In 2015, prices dropped an additional fifty-one percent to $1620 per ton.

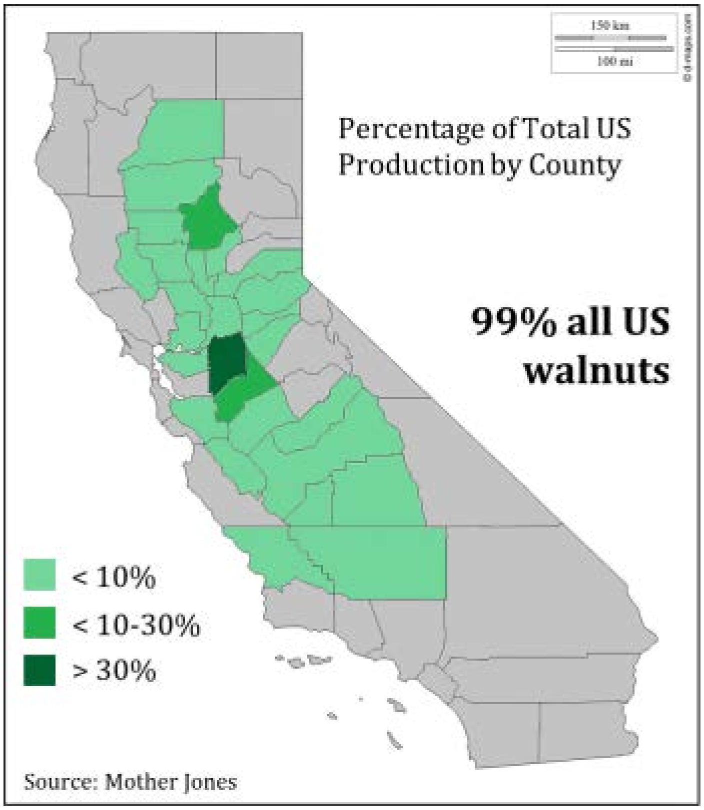

Figure 2: *Distribution of walnut production in California*

Methodology

Trends in energy consumption used in the drying industry was estimated over three time periods: the 1980's, the 2000's, and 2017. These time periods were chosen due to survey data that had been previously collected in 1980 and in 2009 by Martin and Thompson, respectively (Martin, 1980; Thompson, 2009). Cultivation and harvesting, drying and hulling, transportation, and market processing were the four steps in walnut processing considered in this study because it was already known they were energy intensive. In this section, the methodology behind the estimates of energy consumption during these time periods for these four processing steps were discussed.

Cultivation and Harvesting

Cultivation and harvesting, a process that includes pruning, fertilizer application, pest control, collection, and removal from the field, was estimated using published survey data from 1980 (Martin, 1980), 2012 (Kreuger et al., 2012), 2013 (Elkins et al., 2013), and 2015 (Hasey et al., 2015) throughout Northern California. In the estimates used in this report, only the machinery used in the field was taken into consideration. Machinery included mechanical shakers to remove walnuts from the trees, harvest machinery that picks the fallen walnuts from the ground, and irrigation pumping systems if they were included in the survey data. Data estimating the energy use in 2007/2008 and in 2017 were taken from the same reports, so energy consumption for production and harvesting in these time period are identical.

Hulling and Dehydration

Drying and hulling data were also collected via published survey data. Data from 1980 were collected from Luis Obispo County, California and San Benito County (Martin, 1980). These data were averaged over all three regions so that variation in climate was taken into account. Data from this report were reported in kcal/kg; therefore, fraction of energy from natural gas, propane, and electricity (the most common sources of energy during walnut processing (Thompson, 1980)) is not clear. Data from 2009 was collected by Dr. James Thompson for a cost study of walnut production in and Sacramento Valley and San Joaquin Valley North. Estimates of electricity, propane, and natural gas consumption were averaged from data collected from eleven drying facilities in the region. Because sources of energy consumption were given in the report, the team was able to calculate energy consumption with known heating values.

Finally, data from 2017 were collected by the team via a survey administered during the course of the quarter. The survey was based on the survey administered by Thompson et al.; however, questions on quality control were added to the survey upon the request of the team's client. Six facilities were able to give feedback during the quarter, two of which had participated in the 2009 survey. Facilities were asked about production levels, sources and magnitudes of energy consumption, quality control methods, and energy conservation practices.

In order to find contacts to participate in the study, we performed web searches of all the facilities from Thompson's study. We hoped that these would be particularly open to helping us, since they had already given Thompson some information. We contacted them; however only one in eleven facilities participated in our survey. We also tried to find walnut dryers that were not on Thompson's study to increase the sample size of our data; a particularly fruitful source was the yellow pages, with nearly 100 listings for nut processors, some of which were walnut hullers/dryers. We first called facilities in the region to see if they were willing to participate in the study. If they were, they were sent the survey via email. We also requested information from Carl Eidsath, the Technical Support Director of the California Walnut Board, who informed us of a listing of regional advisers online. In addition, Thompson gave us contact information for Rachel Elkins, Pomology Farm Advisor in Lake County. Although these individuals were not able to participate during the course of this project, some have indicated availability to assist in future efforts.

The primary metric extracted from the surveys was total energy use per kilogram of walnuts. This was found using the conversion assumptions detailed in Table 1. Only one facility reported any batches rejected after drying; in this case the reason for rejection was slight under-drying. Additionally, we found an assortment of energy efficiency measures, including upgrading to modern equipment; adding variable flow drives to the dryer fans; air recirculation; moisture monitors; on-site solar; and blowing ambient (rather than heated) air when the weather is warm and dry.

Table 1: *Conversion factors used throughout the report*

Conversions				
Electricity	0.40	\$/kWh	3.6	MJ/kWh
Propane	1.00	\$/Gal	96.36	MJ/gal
NG*	0.89	\$/therm	105.5	MJ/therm

*Natural Gas

Transportation

Transportation and market processing were estimated based on known practices and published data. Explicit studies on these processing steps were not easily found, but estimates were made under the advice of the team's client. Energy associated with transportation was based on an estimate of energy in transportation of all tree nuts and peanuts produced in the United States (Cuellar, 2010). The estimate was based on the relative energy intensity of the tree nut and peanut industry and the energy from the transportation sector to the tree nut and peanut industry. To calculate energy in terms of BTU per ton of walnut production, they adapted the methodology developed by Heller et al. (Heller, 2000). Their model has three main inputs; average distance food travels until it reaches to consumer, average value for energy consumption per mile travelled by the truck (or by airplane if nuts are exported) and the tons of product produced. At the end of their analysis they found that the energetic cost associated with the transportation of tree nuts and peanuts was 7.6 MJ per kilogram of product. Here it was assumed that only parameter that would change over the years is the energy consumption per mile travelled by truck (or any means of transport). Therefore, knowing the trend in energy consumption per mile of truck would enable us to estimate the energy associated with transportation in various years.

Market Processing

Walnut shelling and cold storage were the steps taken into account when market processing was estimated. Energy required to process a kilogram of walnuts in commercially available walnut shelling machines and walnut shell-kernel separating machines were used in the 2009 and 2017 estimates. Data from shelling and separating machines in 1980 were not available, so 2009 and 2017 estimates were used. Energy consumption during cold storage of the walnuts was estimated using the energy consumption of cold storage units used in the agricultural industry. In this report, it was assumed that walnuts were stored at 10 °C [illegible] 1995), so it was reasonable to assume that walnuts stored at this temperature would be stored for up to three months. Technology of common cold storage units had not changes significantly between 2009 and 2017, so estimates for these time periods were identical. Nameplate specifications of a cold storage unit from the 1980's were available from the same manufacturer as the current storage units.

Results

Cultivation and harvesting

During walnut cultivation, about 1.5 MJ of energy are used for every kilogram of walnuts harvested (in-shell basis) in the irrigated Central Valley of California (Martin, 1980). This estimate includes only the machinery used at the walnut cultivator level. Walnuts grown in San Luis Obispo County, California and in San Benito County, California consume 3.8 MJ per kilogram in-shell basis and 1.5 MJ per kilogram in-shell basis, respectively (Martin, 1980). Fluctuations in these values are a result of the varying climate conditions, on average 2.3 MJ were used to cultivate and harvest a kilogram of walnuts. Based on the case studies of walnut cultivation and harvest in the Sacramento Valley in 2012, in the Sacramento Valley in 2015 and in San Joaquin in 2013, 1.2 MJ, and 0.43 MJ, and 0.53 MJ, respectively, were used per kilogram of walnuts cultivated and harvested. On average, 0.73 MJ per kilogram were used to cultivate and harvest walnuts in 2009 and in 2017.

Hulling and dehydration

In 1980, 21.2 MJ were used to dry and hull a kilogram of walnuts. This value is the average estimate from the three regions mentioned previously. Walnuts dried in the Sacramento Valley required 24 MJ per kilogram, walnuts dried in San Luis Obispo County required 15 MJ per kilogram, and walnuts in San Benito County required 23 MJ per kilogram. From the cost study performed by Thompson in 2009, an average of 1.26 MJ per used per kilogram of walnuts. This is the average of the eleven facilities that were surveyed for this study. From our results, 1.19 MJ were used for per kilogram of walnuts. The box plot below illustrates the spread of results from 2008 and 2017 drying survey data. 1980 data were not included in this figure, in order to show the similarities and the spread in the results. These would have been obscured by the 1980 data since those values were over ten times greater.

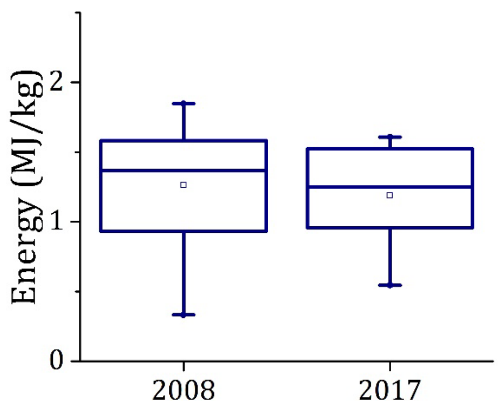

Figure 3: *Distribution of energy needs for drying for most recent survey studies*

Transportation

Energy costs associated with the transportation of tree nuts and peanuts were estimated by Cuellar et al. in 2010 to be 7.6 MJ per kilogram of product (Cuellar, 2010). As mentioned in methodology section to estimate the energy associated transportation costs in 1980 and 2017, we used the energy efficiency index change of freight transportation. The Department of Energy provides the energy efficiency of freight transportation between 1970 and 2011 (DOE, 2012) (see Figure 4). We assumed that energy cost associated with walnut production is directly proportional to this energy efficiency. In 1980 normalized energy efficiency index was 1.1 and in 2009 it was around 0.82. Davis et al. predicted that the energy efficiency increase will be negligible between 2010 and 2020 (Davis, 2007). Based on Davis et al.' study we assume that the estimated for 2009 remain the same for 2017. Using the energy efficiency index in

1980 and energy efficiency index in 2009, energetic costs associated with the transportation was estimated as 10.2 MJ per kilogram of product.

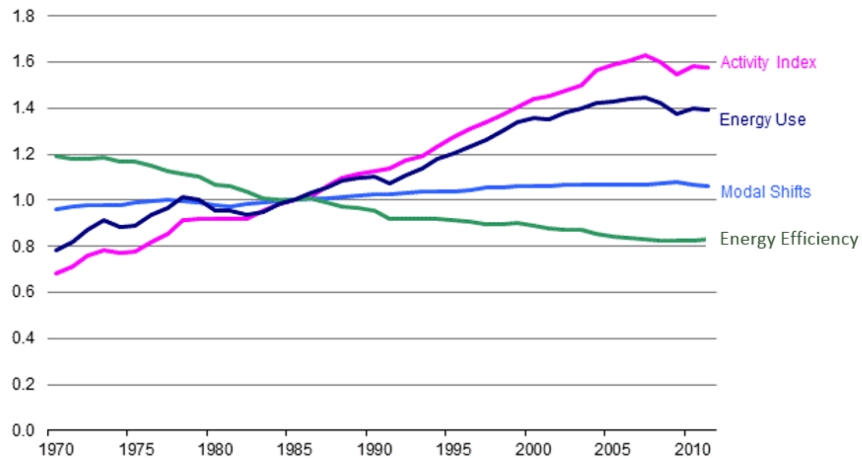

Figure 4: *Total Transportation Activity, Intensity, Energy Use, and Modal Shifts, 1970-2011 (DOE, 2012)*

Market Processing

In 1980, it was estimated that walnuts that were shelled and stored in commercial storage containers for three months at 10 °C required 5.7 walnuts required 3.4 MJ per kilogram if they were shelled and stored under the same conditions. The shelling equipment was able to process 400 kilograms an hour and had a nameplate power consumption of 9 kW. Shelling equipment from 1980 was not found; therefore this equipment was used for shelling estimates over all three time periods (AMISY, 2017). For a single kilogram of walnuts, about 0.023 MJ are used. Similarly, a single value for separator equipment was used across all three time periods. For a separator machine that can process 800 kilograms an hour and as a nameplate power consumption of 2.2 kW, about 0.01 MJ are required per kilogram of walnuts processed. The storage containers used have a storing capacity of 4175 kilograms based on the dimensions of the container and the density of an average walnut (Cold Box, n.d.). The power consumption of the containers were 11 kW for the 1980's container and 6.6 kW for the container used currently and in 2009 (Cold Box, n.d.). These numbers were calculated using a power factor of unity to convert form three-phase AC power to DC power. Therefore, 5.6 MJ were required per kilogram of walnuts processed in 1980, and 3.4 MJ were required in 2009 and in 2017.

Summary of Results and Uncertainties

Table 2 summarizes the quantitative results from this study. From 2009 to 2017, most components of energy use have remained fairly constant. In contrast, all components of production required substantially greater energy in 1980, with the greatest change coming from the drying and hulling step. The reason for this change is not currently well understood.

Table 2: Energy breakdown at each stage in various years reported in MJ/kg

	1980	2009	2017
Drying and Dehulling	21.2	1.3	1.2
Cultivation and Harvesting	2.3	0.7	0.7
Transportation	10.2	7.6	7.6
Market Processing	5.7	3.4	3.4
Total	39.4	13.0	12.9

Figure 5 illustrates the current state of energy distribution from each step. The majority of energy use is clearly dedicated to transportation, since walnuts must be transported across the country and world-wide. Market processing constitutes the next largest portion, followed by drying/dehulling.

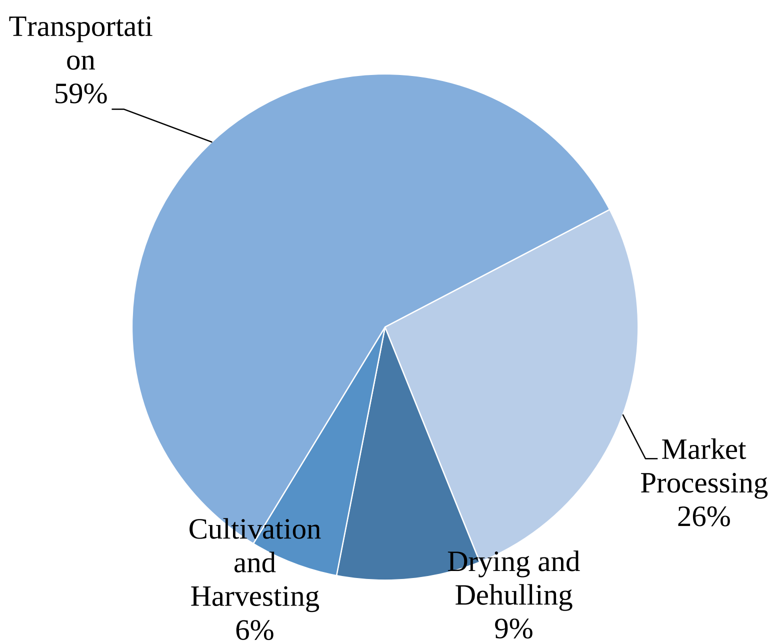

Figure 5: *Energy Breakdown in 2017*

Table 3 summarizes uncertainties and potential inaccuracies introduced in calculating the energy contributions of each production step. The largest uncertainty in the drying/hulling data is due to the small sample sizes of the facilities surveyed. In addition, only facilities processing at least 100 tons were included in our analysis to remove effects stemming from economies of scale. In addition, some facilities reported utility costs whereas others reported kWh and therms, and a constant conversion factor (table 1) was used in all cases. Additionally, not all processing steps may be present in this analysis. Only processing steps that had data the team could extract were given below.

Table 3: *Sources of uncertainties*

Processing Step	Basis for Calculations	Uncertainty
Drying and Hulling	Data sets from 3, 11, and 2 facilities in 1980, 2009, and 2017, respectively	• Small sample size for all three time periods • Different facilities in study • Varying reporting styles
Production and Harvesting	Machinery use in Northern California Irrigation, pesticides, fertilizers not included	• Different facilities may use dissimilar equipment • Irrigation, pesticides, fertilizers not included
Transportation	Energy intensity from transportation sector scaled for all tree nuts and peanuts	• Data from average of all tree nuts and peanuts, including non-California grown nuts • Transportation costs scaled with fuel efficiency • All nuts in US travel same average, scaled by fuel efficiency.
Market Processing	Energy use of shelling machines and cold storage facilities	• Two processing methods accounted for • Storage times may vary • Energy use of equipment • Stored for 3 months at 10°C

Conclusions

From this study, we were able to conclude that drying accounts for 10% of energy consumption during walnut processing. This result show that there is a substantial amount of energy used during hulling and dehydration and that further improvements can be made to optimize this step. Our estimates for drying were consistent with the results from 2009, this shows that not much change has occurred in the industry within the last ten years. However, we did conclude that energy usage in the drying step has decreased by 94% from 1980 levels, and overall walnut processing has decreased by 67% from 1980's levels (see Figure 6). Finally, the team concluded that energy consumption data are not readily available and are hard to obtain. Lack of access to this data makes it difficult to understand the industry and make improvements to area that consume large amounts of energy. By quantifying the steps in walnut processing, our client can better identify where work is best focused and bring to light research opportunities in his field of work.

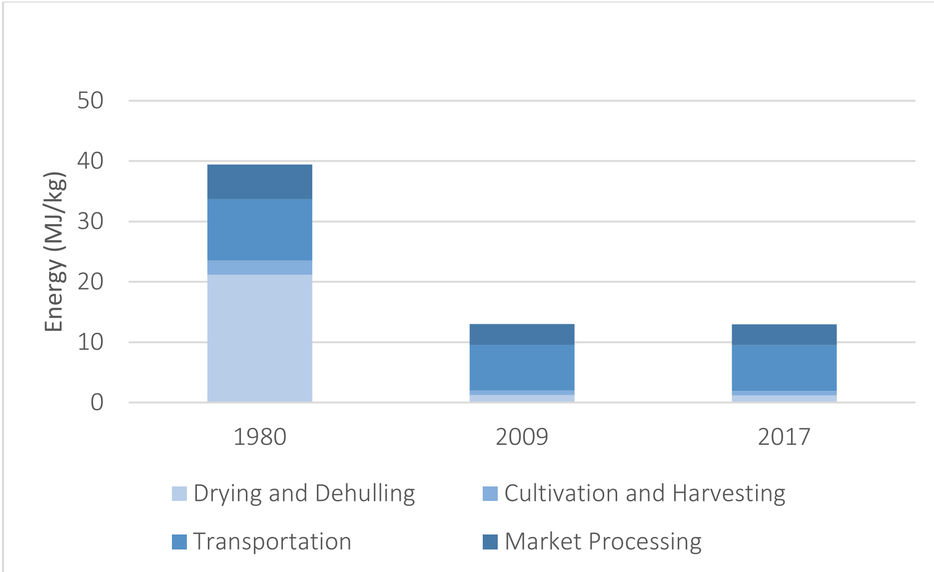

Figure 6: *Energy Consumption per Processing Step*

Recommendations and Future Work

Additional surveys

Through this study, it is apparent that the energy required to dry a ton of walnuts is somewhat variable, with a standard deviation of 33% of the mean. This presents an opportunity for future work in gathering more data and performing further analysis on the process in order to understand what factors account for the wide spread of energy use. To collect these data, we recommend contacting UC Cooperative extension regional advisers, who are a resource to processors that operate in their counties. Hopefully, with a large enough sample size, it will be possible to draw trends among high- and low- energy users. We also recommend modifying the surveys based on feedback from our client as well as the facilities we surveyed to more accurately probe the facility's data: (1) specify at what stage the walnut tonnage is reported: pre-hulling, post-hulling, or post-dehydration. (2) Ask the processors directly to recount factors which influence drying time – for example, walnut variety, time of year, previous year's rainfall, etc. Future work will also be dedicated to understanding the large difference in drying energy use from 1980 to 2009 and 2017.

Utility data

If possible, obtaining utility data of the entire walnut sector would yield a comprehensive picture of energy use, which would yield a more definite target for energy goals. Dr. Donis-Gonzalez has requested all of PG&E's electricity and gas use records from the agricultural sector. He had been negotiating with PG&E to release this data for multiple months before our project began. By the time we came onto the project, PG&E had requested a scope of work detailing why the data was necessary and for what purpose it would be used. We drew up this scope, and then the issue arose of how to properly safeguard the data against misuse – both malevolent and accidental – in order to keep the personal information of the customers whose data was being used safe and confidential. We visited the office of the UC Davis institutional review board (IRB) in Sacramento, who advised us to request that PG&E anonymize the data before sending it to us, which would avoid the demarcation as human subject research. Meanwhile, Dr. Donis-Gonzalez was communicating with the sponsor's office to draw up non-disclosure agreements for this data. During the course of the quarter, it became clear that even with the months of communication between Dr. Donis-Gonzalez and PG&E, much more time was needed before we would be given access to that data. However, we are hopeful that the data will eventually become available and will prove illuminating to this study in the future.

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Appendix A

Facility

1. What kind of dryer do you use?

☐ Stationary bin

☐ Pallet bin

☐ Trailer

☐ Modified grain trailer

☐ Other (please specify) Click here to enter text.

a. Do you have the nameplate specification of your dryer? If so, can you please write its specifications in this box:

Click here to enter text.

b. Did you use air recirculation?
☐ Yes
☐ No

c. Did you use in-bin moisture meters?
☐ Yes
☐ No

If yes, what type? Click here to enter text.

2. What is the drying capacity of your dryer? Click here to enter text.

3. What heat and power sources do you use in your facility?

☐ Natural gas

☐ Propane

☐ Electricity

☐ Other (please specify) Click here to enter text.

Energy use

4. Please specify how much you used of the following, including units (eg therms, kWh)

Natural Gas Click here to enter text.

Propane Click here to enter text.

Electricity Click here to enter text.

Other (please specify) Click here to enter text.

(Survey continues on the next page)

Renovations and quality control

5. What measurements do you make to monitor product quality, during or after dying?

☐ Shell color

☐ Kernel color

☐ Moisture content

☐ Water activity

☐ Rancidity

☐ Other (please specify) Click here to enter text.

6. In the past season, how many tons of walnuts were rejected after drying?

Click here to enter text.

a. What are the reasons that they were rejected?

☐ Shell color

☐ Kernel color

☐ Over-dried

☐ Under-dried

☐ Decay

☐ Cracked shells or kernels

☐ Rancidity

☐ Other (please specify) Click here to enter text.

b. In the past season, what amount did you re-dry? Click here to enter text.

7. If you utilize energy conservation strategies, what are they?

☐ Air recirculation

☐ Moisture monitors

☐ On-site solar

☐ Shut dryer off at night

☐ Other (please specify) Click here to enter text.

(Survey continues on the next page)

8. When was the last time (year) you made any changes to your drying facility with the objective of reducing energy consumption? Click here to enter text.

a. What were the changes? Click here to enter text.

Click here to enter text.

b. Were the changes effective in reducing energy consumption?

c. Approximately what percentage did you save by incorporating the previous strategies?

☐ 1-5%
☐ 5-10%
☐ 10-20%
☐ 20-30%
☐ 30-50%
☐ >50%

Seasonal

9. When does your drying season typically start and end?

Start: Click here to enter text. End: Click here to enter text.

10. How many labor hours were dedicated for drying in the past drying season?

Click here to enter text.

11. How many walnuts did you process in the past drying season?

Click here to enter text.

12. What varieties of walnuts do you dry?

Click here to enter text.

Other equipment; repair costs

13. Do you use an electronic sorter?

☐ Yes

☐ No

14. If you are a hulling facility, what hulling equipment do you use?

Click here to enter text.

15. What were your repair costs for the following?

Dryers Click here to enter text.

Hullers Click here to enter text.

Electronic sorting systems Click here to enter text.

Other Click here to enter text. Click here to enter text.