# ENERGY EFFICIENCY IN FOOD PROCESSING IN THE SOUTHERN REGION

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Food processing accounts for a large part of the total energy consumed in the food and fiber system, second only to household preparation. Havlicek and Capps emphasized that processing and distribution of food and fiber require 12 to 17 percent of the total U.S. energy budget. Thus far, research on energy use by agriculture in the southern region has concentrated on production of raw products at the farm level (Debertin and Pagoulatos) and consumption of food in the home (Lovingood and Goss; Rhee and Drew). The large processing and distribution network has been generally excluded from analysis because of a lack of information on energy used in these industries. Comprehensive data bases on energy use in food processing have been relatively limited because of the imperfectly competitive nature of food processing industries and because of unfavorable costs and benefits of compiling such information. Because of a lack of accurate and reliable data, little is known about the behavioral relationship of energy use in food processing and distribution.

The general objectives of this paper are to describe energy use in food processing and to develop an economic model to explain differences in energy efficiency among food processing industry groups. Energy efficiency is defined as average product of energy or the amount of processing a firm extracts from a standard unit of energy. The model will be used to analyze processor sensitivity to energy price changes, energy efficiency effects of plant size, and relationships between market power and energy consumption patterns. This research focuses on direct energy expenditures made by food processors. Major energy-use categories generally include raw product assembly; food processing, preparation, and storage; maintaining plant and office facilities, and finished product distribution.

## PREVIOUS STUDIES

Recent studies have not shown a conclusive relationship between energy use and food processing. Where the analysis has been more rigorous, the findings tend to be industry specific. Jones and Lee identified factors influencing energy consumption by broiler processing plants in the South and determined the impact of those factors on production costs. Using a regression model, they found that 74 percent of the variation in energy consumption rates could be explained by average volume of output, temperature, plant capacity utilization, and energy prices.

Unger selected 14 firms from 44 industries in the food and kindred product group of the government's Standard Industrial Classification (SIC) system to study levels and variations in energy use. His analysis emphasized the sensitivity of food processing to natural gas prices and supplies. Using a Pearson chi-square statistic, Gesell compared energy source efficiencies with size of plants in Pennsylvania to determine if energy efficiencies are related to plant size. Results indicated that large firms tend to be more energy efficient than small firms.

Whittlesey and Pfeiffer measured the impacts of energy supply interruptions and found that for energy supply reductions greater than 10 percent, output would be reduced by more than 10 percent. A 100-percent increase in the price of energy was estimated to increase processing costs by less than 5 percent. Unger cited differences in product mix and functions performed at plants as factors influencing energy efficiency. Casper indicated that regulations established by federal agencies have reduced energy efficiency of some processors by 1 percent.

Sinclair et al., measured the intensity of energy use of manufacturing establishments in South Carolina in order to determine the potential for energy savings. Their study found that a large potential for energy savings could be realized by some establishments with the substitution of non-energy inputs for current energy inputs.

## THE CURRENT STUDY

To learn more about energy use in food processing, a national energy survey was undertaken by the U.S. Department of Agriculture, Economics Statistics and Cooperative Service in cooperation with four land-grant universities, responsible for individual regions. In the fall of 1978, 8,198 surveys were mailed to food processors selected at random from the Agricultural

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Stabilization and Conservation Service Food and Feed Facility Establishment File. A total of 1,327 responses were received nationally, with 296 from the southern region. The analysis that follows is based on responses from: Alabama, Arkansas, Florida, Georgia, Louisiana, Kentucky, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia (Booth).

From a descriptive standpoint, the survey revealed several important characteristics of food processors in the region. The importance of natural gas in food processing is shown in Table 1. Six of the eight industry groups surveyed reported natural gas as their dominant energy source.

In addition to questions on energy source and levels, processors were asked about energy conservation performance: the results are shown in Table 2. Of the 82 percent reporting that they had made a conscious effort to reduce energy use during the previous year, 2 percent reduced energy consumption by 25 percent, 8 percent reduced consumption by 16–25 percent, 33 percent reduced consumption by 5–15 percent, and 37 percent by 0–5 percent. Cane sugar processors reported the greatest conservation success, while the least conservation success was reported by dairy products processors.

**TABLE 1.** Distribution of Energy Usage by Source and Industry Group (Percentage of Total BTUs Attributed to Each Fuel), 1977–78

| Industry Group | Energy Source | | | | | |
|---|---|---|---|---|---|---|
| | Gasoline | Diesel Fuel | Fuel Oil | Natural Gas | LP | Electricity |
| | percent[a] | | | | | |
| Meat Industry | .19 | .09 | .10 | 99.42 | .01 | .10 |
| Dairy Products | 13.80 | 8.40 | 13.44 | 47.83 | b | 16.53 |
| Canned Foods | 1.12 | 1.00 | 17.80 | 67.28 | .60 | 12.20 |
| Grains, Flours, and Meals | 14.15 | 9.70 | 4.75 | 52.70 | 2.20 | 16.50 |
| Cane Sugar | .82 | 4.60 | .28 | 40.30 | b | 54.00 |
| Oil Mills | 1.50 | .72 | 21.90 | 57.94 | .44 | 17.50 |
| Food Preparations | 7.25 | 16.96 | 6.84 | 37.65 | 8.80 | 22.50 |
| Wholesalers and others (not elsewhere classified) | 8.70 | 8.10 | 7.40 | 23.10 | 1.50 | 51.10 |

[a] Sum of percentages by fuel source may not equal 100 percent due to rounding.
[b] Negligible, less than .01%.

**TABLE 2.** Energy Conservation Performance in Selected Food Processing Firms, 1977–78

| Industry Category | No. of Firms | Percentage Which Reduced Energy Use By: | | | | | |
|---|---|---|---|---|---|---|---|
| | | >25% | 16-25% | 5-15% | <5% | No Reduction | No Response |
| Meat Industry | 39 | 0 | 10 | 36 | 30 | 8 | 8 |
| Dairy Products | 19 | 0 | 0 | 37 | 47 | 0 | 16 |
| Canned Foods | 26 | 4 | 4 | 30 | 23 | 0 | 23 |
| Grains, Flours, and Meals | 64 | 2 | 8 | 33 | 42 | 6 | 11 |
| Cane Sugar | 7 | 43 | 29 | 0 | 0 | 0 | 0 |
| Oil Mills | 15 | 0 | 13 | 20 | 40 | 0 | 27 |
| Food Preparations | 14 | 0 | 14 | 36 | 29 | 7 | 14 |
| Wholesalers and others (not classified elsewhere) | 85 | 1 | 7 | 31 | 39 | 9 | 13 |
| ALL PROCESSORS | 269 | 2.2 | 8.2 | 32.7 | 37.2 | 6.3 | 13.4 |

This energy conservation performance indicates that processors have the capability of reducing energy usage, given proper incentives. However, variation in energy input combinations and conservation success across industries suggests that future energy policies aimed at improving energy efficiency are likely to have unequal impacts on these firms.

Processors expressed confidence in their ability to deal with future energy problems. When asked about dual-firing capability, 24 percent of the industry categories surveyed reported that they had dual firing equipment.[1] Only 18 percent of those surveyed made attempts to increase storage capacities during the year, and only 28 percent had contingency plans for future energy supply shortages. Finally, only 8 percent of the respondents reported having problems obtaining energy supplies during the previous year.

The survey data on energy use and conservation by food processors have several implications for the model developed in the next section. Variation in the level and source of energy used by processors suggests that there may also be variation in energy efficiency among firms. Hence, this research attempted to identify factors contributing to energy performance variation. The dominance of natural gas in food processing was used as support for specifying the firm's fuel mix on the basis of natural gas consumption relative to other energy sources. Differences in the cost per BTU among energy sources leads to variation in the average cost per BTU paid by individual firms with dissimilar energy input combinations. Consequently, energy costs were included in the general model. Finally, varying degrees of success in energy conservation among processors provided the problem setting to which the model is addressed: Why do some firms process more food per given unit of energy than others?

## FACTORS ASSOCIATED WITH DIFFERENCES IN ENERGY EFFICIENCY

In addition to informing food processors of their relative performance in using scarce energy sources, this research developed a model to predict how processors should respond to changes in selected energy and non-energy variables. A conceptual model was developed using production-cost theory, theories of imperfectly competitive markets, and empirical evidence of functional relationships from previous research. The-

[1] Dual-firing capability refers to boiler systems that can be readily adapted to use natural gas or fuel oil.

ory and empirical evidence suggested that a model to explain energy efficiency should include as a minimum: (1) an estimate of what firms pay for energy; (2) some variable representative of plant size; (3) a measure of fuel mix because of relative differences in fuel productivity (in terms of BTUs); (4) some variable to account for a firm's ability to use more efficient fuels; and (5) an estimate of the firm's market share, under the assumption that the degree of market power is directly related to the firm's ability to pass energy price increases along to customers.

This research made a distinction between energy efficiency and economic efficiency. Energy efficiency, as defined by average product of energy, is a technical or engineering concept, related to, but not synonymous with the concept of economic efficiency. The level of technical efficiency achieved by an input is dependent upon the relative importance of that input in production and becomes secondary to that firm's profit maximizing behavior. In this study, it is assumed that firms are economically efficient or operate in such a manner as to fulfill the first-order conditions for profit maximization. Using factor-product analysis, average product or energy efficiency is related to marginal product and declines throughout the rational stage of production (Stage II). Subsequently, the theoretical justification for including many of the following variables rests on the relationship among marginal product, average product, and profit-maximizing adjustments.

It was first necessary to choose the "best" estimate of energy efficiency from a variety of ratios used in the literature (Sinclair et al.; Jones and Lee). Pounds of food processed per million BTUs of energy was used as the measure of energy efficiency (Sinclair et al., p. 8) because of differences in energy rates found to exist within and across industries (Booth). In a production economics context, this dependent variable is comparable to average physical product. Explanatory variables in the model included:

*Fuel Price* = Price or cost per million BTUs. The more costly a production input becomes, the more sparingly it is used in production or, in the case of energy, the more energy efficient a firm becomes. As shown in Figure 1, a higher energy price can be illustrated as an increase in the marginal factor cost of energy ($MFC_e$) in production analysis. At higher energy prices, firms will equate marginal factor cost and marginal value product at lower levels of fuel use in order to maximize profits. A positive relationship is expected.

*Natural Gas* = Percentage of total fuel costs accounted for by dollars spent for natural gas. As the dominant fuel of most firms, this variable represents the firm's fuel mix and level of dependence on natural gas. Because of the relatively high efficiency and low cost of natural gas per BTU and the logic presented in the previous variable, a negative relationship is expected.

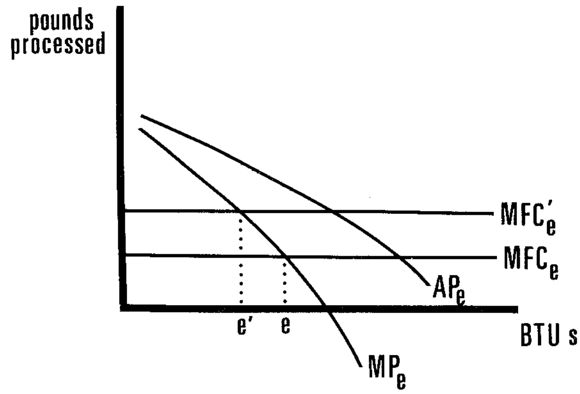


**FIGURE 1.** Theoretical Relationships Between Marginal Product of Energy and Energy Cost under Conditions of Profit Maximization

*Output* = Output in tons for the 12-month period. The variable is used to represent size and to determine whether larger firms are more energy efficient. Changes in output imply changes in plant size (plant size, however, is assumed to remain constant when interpreting other variables in the model). In reference to Figure 1, average product for the output variable must be interpreted as points on various total product curves, each representing a scale of plant, rather than movement along a particular total product (average product) curve as implied by the remaining variables. Theoretically, greater total product curves for larger scale plants are associated with larger average products at given input levels. This rationale and findings from other studies suggest a positive relationship should be expected (Gesell; Jones and Lee).

*Energy Costs as Percent of Sales* = Percentage of total production costs consisting of energy costs or the degree of energy intensity (Sinclair et al.). This variable serves as a proxy for the energy and non-energy input mix. The relationship between energy and non-energy inputs and their impacts on energy efficiency have been studied and shown to be significant in agricultural production (Debertin and Pagoulatos). Assuming that processors are producing in Stage II under conditions of declining marginal product for energy, energy intensive processors are expected to experience a greater degree of diminishing returns to energy relative to non-energy inputs. The effect of diminishing returns has a negative effect on average physical product. This relationship between input combinations and energy efficiency is shown in Figure 2. Firms use some combination of energy and non-energy inputs for food processing. As firms increase the use of energy inputs from e to e′, the marginal rate of technical substitution of energy for non-energy inputs decreases along with the average product of energy from $AP_e$ to $AP'_e$. A negative relationship is expected.

*Market Share* = Concentration ratio as defined by the percent of total value added by processing accounted for by the 20 largest companies in each industry. To estimate industry concentration ratios, alternative measures of processing activity were considered, including total sales and value added. Since the value of processed product reflects both production and processing costs, total sales do not accurately reflect the level of processing activity in an industry. Value added by processing was selected as a more accurate indicator of processing activities and was used to construct concentration ratios. The greater the percentage of total value added by processing by the 20 largest firms in the industry, the more concentrated the industry. Firms in concentrated industries were thought to have the ability to pass along energy price increases. A negative relationship was expected.

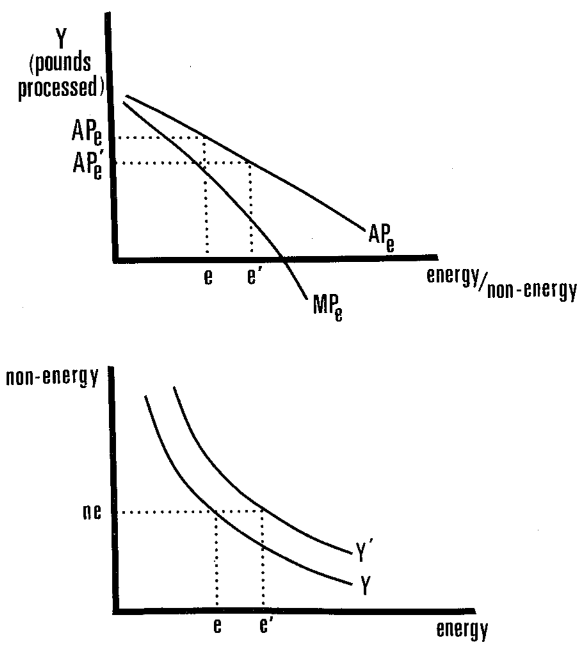


**FIGURE 2.** Theoretical Relationship Between Average Product of Energy and Marginal Rate of Technical Substitution, Energy for Non-energy Resources

*Storage Capacity* = Total storage capacity in gallons.[2] This variable is designed to capture the extent to which firms maintain supplies of available fuels and insulate themselves from market price and supply instabilities. Firms that can maintain reserve energy supplies should be less sensitive to market pressures. A negative relationship is expected.

*Industry* = Industry type as classified by SIC codes. Binary variables were used to determine whether separate models should be estimated for each industry group. Since industries perform different functions in producing different products, some specification of industry differences was included. No a priori expectations were hypothesized concerning the nature of these relationships.

## ANALYSIS

Ordinary least-squares regression was applied to the model discussed above. There was no a priori or theoretical reason for selecting a particular functional form in this research. A semi-log function (log of the dependent variable only) was selected after discovering that this non-linear form yielded better estimates than the more conventional linear form.

The equation estimated in the analysis was

$$(1) \quad E = \exp\left[\propto + \sum_{i=1}^{k} X_i\beta_i + u\right]$$

where:

$E$ = average product of energy
$X_i$ = independent variable
$\beta_i$ = beta coefficient for $X_i$
$u$ = normally distributed random error term with mean zero and finite variance

Given the semi-log equation (1), mean coefficients of elasticity can be derived as follows:

$$(2) \quad \eta = \frac{\partial E}{\partial X_i} \cdot \frac{\bar{X}_i}{\bar{E}}, \; i = 1,\ldots,k$$

where:

$\eta$ = mean coefficient of elasticity for the $i^{th}$ independent variable
$\bar{X}_i$ = mean value for the $i^{th}$ independent variable

[2] Some relationship was thought to exist between storage capacity and fuel mix because natural gas and electricity are not generally stored at the firm level. Ordinary least squares estimates of the unique relationship between storage capacity and energy efficiency are valid when fuel mix and other explanatory variables are held constant at their means.

$\bar{E}$ = mean value of dependent variable

$$\frac{\partial E}{\partial X_i} = \exp\left[\propto + \sum_{i=1}^{k} \bar{X}_i\beta_i + u\right] \beta_i$$

Regression results shown in Table 3 indicate that all parameter estimates were consistent with a priori expectations. Only one dummy variable for industry classification was included in the final equation. Also shown are elasticity estimates when variables are evaluated at their means.

The elasticity estimates are particularly useful for determining relationships between energy use and food processing and can be interpreted as follows. For example, if the cost per million BTUs increases 10 percent, then energy efficiency increases by .8 percent, or by 11.5 pounds per million BTUs. Or, more realistically, if the real cost of gasoline increases by 50 percent from $1.00 to $1.50 per gallon, then firms can be expected to process 100 more pounds of processed output per million BTUs,[3] or an increase in energy efficiency of 6 to 7 percent. Similar interpretations can be made regarding other explanatory variables in the equation.

Natural gas costs as a percentage of total fuel costs were included in the model to capture fuel mix. Historically, natural gas has been a relatively inexpensive fuel compared to electricity, and has become the dominant fuel in food processing. The direction and magnitude of the coefficient for natural gas indicates that domestic price controls on natural gas have held down energy efficiency in food processing. As natural gas costs increase from deregulation, processors will be forced to use natural gas more efficiently.

The positive relationship between plant size and energy efficiency is taken as evidence that size advantages exist in achieving energy efficiency. Some of these size advantages are thought to result from economies of size and input indivisibilities in energy technologies. New energy-saving technology may be more adaptable to large-scale operations, which are in a better capital position to purchase such inputs.

The percentage of energy costs, which measured the energy intensity of the firms, was found to be significant. The negative relationship between energy intensity and energy efficiency is explained by factor-factor production analysis. As a firm becomes more energy intensive, the marginal rate of technical substitution between energy and non-energy inputs diminishes, or the marginal contribution of additional energy inputs diminishes relative to that of non-energy inputs. This declining marginal productivity of energy serves to reduce the average productivity of energy. In practical terms, this means that the substitution of non-energy related inputs (insulation or processing labor) will increase the energy efficiency of the plant.

Market share is interpreted as an estimate of concentration or, conversely, the degree of competition in the industry. Results indicated that firms in concentrated industries were less energy efficient, showing evidence of their market power and ability to pass along energy price increases to consumers. Energy policies that increase costs to firms in concentrated industries should take into consideration the impact of such increases on consumer prices.

Energy efficiency was also shown to be related to storage capacity, or the ability to have fuel available at all times. Among firms with similar energy input combinations, firms with fuel storage capacity tended to be less energy efficient than those without such capacity. Incentives for conservation are lessened by storage facilities, which offer some insulation from market shocks, including supply shortages or price fluctuations. The true opportunity cost of fuel may not be appreciated when such fuel is available "free-at-point of-use" to the firm's employees.

Except for meat processors, interindustry differences per se in energy use and conservation (Tables 1, 2) were not found to be significant determinants of energy efficiency. This does not

**TABLE 3.** Factors Associated with Differences in Energy Efficiency Among Food Processors, 1978

| Name | Description | Mean | Estimated Coefficient[b] | Coefficient of Elasticity |
|---|---|---|---|---|
| (Dependent Variable) | | | | |
| ENERGY EFFICIENCY | lbs. processed per million BTU | 1406.32 | | |
| (Explanatory variables) | | | | |
| 1. CONSTANT | . | | 7.90 (24.65)*** | |
| 2. ENERGY PRICE | Price Per Million BTU | 6.73 | .019 (1.67)* | +.133 |
| 3. NATURAL GAS | Percentage of total energy costs allocated to natural gas | 16.19 | -.018 (-3.17)*** | -.285 |
| 4. OUTPUT | Total tons processed during 12 months | 33652.40 | 6.80[a] (3.27)*** | +.229 |
| 5. % ENERGY COSTS | Percentage of total costs allocated to energy costs | .07 | -1.65 (-2.57)** | -.113 |
| 6. MARKET SHARE | Concentration ratio | 49.19 | -.010 (-1.91)* | -.504 |
| 7. STORAGE CAPACITY | Total storage capacity in gallons | 25325.90 | -4.38[a] (-2.85)*** | -.115 |
| 8. INDUSTRY | Binary for industry = 1 if meat industry; 0 if otherwise | .17 | -1.21 (-3.72)*** | |

$R^2$ = .2739; Number of observations = 146

[a] value multiplied by $10^{-6}$
[b] t values in parentheses
*** significant at the $\alpha$ = .01 level
** significant at the $\alpha$ = .05 level
* significant at the $\alpha$ = .10 level

[3] One million BTUs is approximately equivalent to 8 gallons of gasoline.

imply that technological and processing techniques do not effect energy efficiency, but rather, these engineering differences may have been captured by other explanatory variables in the model. For example, an estimate of processing technology is captured by size, energy intensity, and cost variables. The level of technology used by a firm is related to energy costs and the firm's ability to purchase new technology.

Because of differences in some explanatory variables across industries, further analysis may be necessary to predict interindustry impacts of national energy policies. Policies aimed at increasing energy efficiency in one industry may be ineffective or may create hardships for other industries. Such differential impacts might result from differences in energy fuel mix and market power across industries.

The independent variables in the model explained 27 percent of the variation in energy efficiency, thus, more than 70 percent of the variation remained unexplained. This unexplained variation was partially attributed to the exploratory nature of the research and the cross-sectional nature of the data. Because of its low predictive power, the model is not appropriate for predicting or forecasting energy efficiency. A model with better forecasting power would be needed in order to make reliable forecasts.

The value of the model must be interpreted in light of the overall objectives of the research. This research was primarily concerned with the testing of specific hypotheses about explanatory variables. For testing hypotheses about specific explanatory variables, the model gives useful directions of energy related behavior in food processing. Despite a low $R^2$, the model appears to be theoretically sound.

## SUMMARY

Research on energy use in food processing has been fairly limited. Consequently, little is known about the behavior of food processors concerning energy decisions. This study indicated that food processors have experienced different levels of energy efficiency and have had varying degrees of success in their energy conservation efforts.

Survey data were used to construct a measure of energy efficiency. Next a general model was designed to explain differences in energy efficiency. The particular level of energy efficiency achieved by the processor was shown to be a function of the firm's profit-maximizing behavior. Likewise, changes in energy efficiency levels were shown to be influenced by factors that changed the profit maximizing level of production. Energy efficiency among processors was found to be related to energy prices, energy and non-energy input combinations, size of plant, the degree of competition within industries, storage capacity, and industry classification. Coefficients of elasticity were computed from model estimates and used to predict how energy efficiency among processors would be affected by changes in various market and non-market factors.

## POLICY IMPLICATIONS

The general model of energy efficiency presented in this paper gives policymakers a better understanding of some probable impacts of selected future energy policies. Foremost in energy policy debates is deregulation of energy supplies and prices. This research indicated that when deregulation of energy supplies and/or prices lead to higher energy costs for food processors, somewhat greater energy efficiency will result; however, these energy savings tend to be small. From an energy efficiency perspective alone, deregulation appears desirable. However, the food and fiber system has multiple goals, and the benefits of achieving greater energy efficiency must be weighed against expected costs, which may not be evenly distributed between processors, consumers, and producers. In particular, policymakers must make a trade-off between policies that permit wasteful usage of energy, with current food prices, and policies for efficient usage of energy, which lead to higher food prices. Further research is needed to determine the short and long run consequences of energy pricing policies on derived producer demand, consumer food costs, and ultimately, on the standard of living.

This research was also concerned with physical and institutional mechanisms that insulate processors from market pricing signals and market competition. The presence of fuel storage facilities and market power were found to be disincentives to energy efficiency. Policymakers should discourage the hoarding of fuels when such hoarding discourages energy efficiency and disrupts energy markets and price mechanisms.

The ever-present concern over market power in food processing takes on additional significance in the context of energy efficiency. This research indicated that market competition encouraged energy efficiency. Although more studies of the relationship between market power and energy use are needed, policymakers could also take into account the probable impacts of market concentration on energy efficiency in their arguments for maintaining competition in food processing.

Food processors must satisfy growing consumer demand for their services in the face of higher energy costs. Better knowledge of the factors affecting energy efficiency can be used to complement our understanding of energy-related decisions in food production and consumption, and to enable policymakers to make sound energy management decisions for the future of the U.S. food and fiber system.

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