

# Wasted Food, Wasted Energy: The Embedded Energy in Food Waste in the United States

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This work estimates the energy embedded in wasted food annually in the United States. We calculated the energy intensity of food production from agriculture, transportation, processing, food sales, storage, and preparation for 2007 as  $8080 \pm 760$  trillion BTU. In 1995 approximately 27% of edible food was wasted. Synthesizing these food loss figures with our estimate of energy consumption for different food categories and food production steps, while normalizing for different production volumes, shows that  $2030 \pm 160$  trillion BTU of energy were embedded in wasted food in 2007. The energy embedded in wasted food represents approximately 2% of annual energy consumption in the United States, which is substantial when compared to other energy conservation and production proposals. To improve this analysis, nationwide estimates of food waste and an updated estimate for the energy required to produce food for U.S. consumption would be valuable.

## Introduction

Recent food shortages, blamed in part on the growth of the biofuels industry (1, 2), have created a new awareness of the relationship between food and energy. Food is not only a form of energy but also a consumer of fossil energy in its production, transportation, and preparation. Historically this has been a positive relationship: the last 50 years have seen increased agricultural productivity thanks to the adoption of new technologies and inputs (3), which are largely based on fossil fuels. The increase in the energy intensity of agriculture has brought with it unprecedented yields with minimal human labor. Productivity improvements have been achieved through a variety of means, including mechanization of the agriculture sector, improved fertilizers, more resilient crops, and the development of pesticides (4), all of which rely on fossil fuels.

Prior estimates for the amount of energy consumed by the United States (U.S.) to produce food range from 10.5% (5) to 14.5% (6) of annual energy consumption. The newest estimate, released in March of 2010, estimates that 15.7% of energy consumption in 2007 was used to produce food (7). Despite the significance of the food system as an energy consumer, few estimates for the energy intensity of the

system are available, and, despite the enormous energy investment we make in food production, the USDA reports that about 27% of available food was wasted in 1995 (8). This estimate does not include food wasted on the farm, in fisheries, and during processing and relies on outdated food consumption and waste data, some of which is from the 1970s. Because of economic and population growth, the total amount of food production and consumption has grown since the latest food loss study for 1995 (9), and the portion of income Americans spend on food has dropped (10, 11). Consequently we expect the current amount of food wasted to be higher both relatively and absolutely as compared to the USDA's 1995 estimates. Since food production requires about one-tenth of the energy consumed annually in the U.S., the energy embedded in wasted food might also correspond to a significant portion of energy consumption in the U.S. and represents an opportunity for avoided energy consumption.

Because of the desire to reduce greenhouse gas emissions, concerns about fossil fuel availability, and the expected increase in population (12), the reliance of food on fossil energy sources has become more scrutinized. In order to better understand the relationship between food and energy, a current estimate for the energy embedded in food production is needed as well as a calculation of the energy that is lost in wasted food. No such study using current data has been identified in the literature. Consequently this work seeks to fill that knowledge void and provide important data that will quantify both the energy required to produce food in the U.S. in 2007 and the energy embedded in wasted food.

This work will calculate the amount of energy used to produce food from agriculture, through transportation, processing, retailing, and finally for preparation and consumption. These data will then be combined with food loss factors from the USDA (8) to calculate the energy lost in wasted food. Because the data available on food production and food waste are from different years, all data will be considered as a percentage of annual energy production for that year and extrapolated to obtain an estimated 2007 energy value.

**Energy for Domestically Consumed Food.** First, we calculated the energy required to produce food. Despite various literature sources that estimate the energy required for U.S. food production (5, 7, 13, 14), we recalculated this value for 2007 to generate an estimate organized in a way that is compatible with the available food waste data. For our estimate of the energy required to produce food consumed in the U.S. we compiled data from various sources including government reports and scientific literature. Data for the energy consumed in food production is mostly from the year 2002, whereas the available data on food loss is from 1995 and food quantities are given for 2004. In order to minimize error, the energy values for food production were determined for 2002 and then scaled to estimate 2007 values. A summary of the results is shown in Table 1, along with the year of the data source and citation. The Supporting Information (SI) contains details of our methodology.

While we expect that all values listed in Table 1 have significant uncertainty, none of the published data include error estimates. A range of error is not given in Table 1 unless we have multiple estimates for a single value in Table 1 in which case we use the standard deviations of the multiple estimates to approximate the error. For other listings, in Table 1 when we have a single estimate (that is, for all categories except transportation and nitrogenous fertilizers included in agricultural chemicals, fuel, and

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**TABLE 1. Food Production in 2002 Required at Least 7790 ± 732 Trillion BTU in the U.S.<sup>a</sup>**

food production steps [index = <i>i</i> ]	energy [trillion BTU]	year	source
ag. chemicals, fuel, electricity	1160 ± 69	2002 (adjusted)	see the <i>SI</i>
fisheries	18	2000/2002	(15–17)
aquaculture, domestic	8.8	2002 (adjusted)	(18, 19)
aquaculture, imported	55.8	2002 (adjusted)	(18, 20)
<b>agriculture total [1]</b>	<b>1240 ± 70</b>		
transportation, all modes	1650 ± 520	2002 (adjusted)	(13, 18, 21–25)
<b>transportation total [2]</b>	<b>1650 ± 520</b>		
food processing	1120	2002	(18)
<b>processing total [3]</b>	<b>1120 ± 220</b>		
food services and sales	1530	2003	(26)
packaging	684	2002 (adjusted)	(5, 18)
residential energy consumption	1570	2001	(5, 18, 27)
<b>food handling total [4]</b>	<b>3780 ± 460</b>		
<b>total</b>	<b>7790 ± 730</b>		

<sup>a</sup> The food handling step was the biggest contributor to the total. The index “*i*” is used as an index for the four different food production steps for the calculations using eqs 1 through 4 and equation S11 (see above and the *SI* for more information).

electricity, see the *SI* for details) we use a 20% uncertainty because it is the average of the error estimates that we were able to calculate for nitrogenous fertilizers (8% error) and transportation (32% error). Ultimately, the 20% error bars we use are arbitrary, since they rely on two varying estimates of error for nitrogenous fertilizer production and food transportation. We expect our energy estimate to have some range of error because of the assumptions and estimates we make throughout our analysis. Nonetheless, we rely on methodologies published in the scientific literature and data sets from the U.S. government, which we consider reliable sources. Therefore we use the 20% error bars to not overstate the accuracy of our estimate but also to not undermine the validity of our work in estimating the energy required to produce the food consumed in the U.S. Using this method for estimating error for individual values we calculate the total uncertainty in the energy consumption in 2002 to be ±730 trillion BTU after propagating the calculated and 20% error values throughout all calculations. [To estimate total uncertainty, we used the following relationship:  $U_{tot} = (\sum u_i^2)^{1/2}$ , where  $U_{tot}$  is the total uncertainty and  $u_i$  is the uncertainty for each of the steps listed in Table 1.] The energy estimate for food production scaled to 2007 energy values is 8080 ± 760 trillion BTU. In 2002 and 2007 the total energy consumption for the U.S. for all sectors was 97,900 trillion BTU and 101,600 trillion BTU, respectively (18). These values were used to scale the energy for food from 2002 to 2007 assuming linear increases in energy consumption for the U.S. and for food production.

Our estimate for the energy required to produce the food consumed in the U.S. amounts to approximately 8% of the energy consumed annually for all uses. Heller and Keoleian calculated the energy consumed to produce food throughout its lifecycle for the late 1990s as 10,200 trillion BTU (5), constituting 10.5% of annual energy consumption. Pimentel et al. report in 2003 that 14.5% of the U.S. annual energy consumption is used to produce food; the year for the Pimentel estimate is not clear (6). In a 2010 report Canning et al. found that food production required 15.7% of 2007 energy consumption in the U.S. The Canning estimate includes energy estimates for the same steps and categories of the food system as we do but draws a larger boundary around the food system than our study does. For example, Canning’s report includes several energy inputs that we did not include, such as the energy used by consumers to purchase food (fuel for driving to food stores), and the energy required to produce modes of transportation used in food procurement. Canning et al.

also use a more complex method for scaling their food energy estimates to different years, which does not assume linear energy growth in the food system in line with total energy use in the U.S.

The energy required to dispose of food waste was not included in this study. Food scraps made up 12.4% of total municipal solid waste generated in 2006 (28), but a value for the energy required for municipal solid waste disposal was not found in the literature. Compared to the estimates from the Heller et al., Pimentel et al., and Canning et al. publications, the energy estimate presented here is lower but within 25% of Heller’s work. Consequently, the energy estimate presented in Table 1 can be considered a lower bound estimate of the energy required for food production, consumption, and disposal.

**Energy Embedded in Wasted Food.** To calculate the energy embedded in wasted food we use 1995 food loss data provided by the USDA for ten food categories, shown in Table 2. These data show that grain products, dairy products, fresh vegetables, fresh fruit, and fats and oils are, proportionally, the most wasted foods.

The USDA report calculates food loss by retail and food service establishments and by consumers. As the authors of the USDA report note, there are significant food losses from other components of the food processing chain that are not accounted for. These include losses on the farm, from fishing, and during processing. Fishing waste could be a significant contributor to overall food waste; it is estimated that worldwide approximately 23% of fish landings are bycatch, which are thrown back into the ocean, usually already dead or dying, instead of being sold and consumed (29). The 1997/95 USDA report also makes use of food waste factors from previous reports, some from the 1970s. The USDA applied food loss factors to food availability data for 1995 to arrive at the percentage results shown in Table 2 (5). The methodology used as well as the age of the food loss estimate implies a large margin of error in these data both for 1995 and for the current analysis. We expect that current food loss in the U.S. is greater (absolutely) than the amount estimated in the 1995 USDA work, but assume, for our calculations, that the relative food waste percentages are the same in 2007 as for 1995. It is possible because of economic growth and the declining price of food as a portion of discretionary income that relative food waste percentages actually increased over that time span. Due to unaccounted food losses and the potential for increased waste due to economic conditions we expect the results in the present analysis to represent a lower bound.

**TABLE 2. The USDA Estimates That 27% of Edible Food Was Wasted in 1995 with Fresh Foods (Fruit, Vegetables, and Dairy Products) and Fats and Oils Being the Most Wasted Food Categories (8)<sup>a</sup>**

commodity [index = <i>j</i> ]	edible food supply [billion lbs]	total loss [billion lbs]	% of total [%] ( <i>f<sub>j</sub></i> )
grain products [1]	45.6	14.6	32.0
fruit [2]			
fresh	22.4	7.2	32.0%
processed	25.9	4.2	16.0%
total fruit	48.3	11.3	23.4%
vegetables [3]			
fresh	36.8	11.8	32.0%
processed	26.2	4.2	15.8%
total vegetable	63.1	15.9	25.3%
dairy products [4]			
fluid milk	54.5	17.4	32.0%
other dairy products	21.8	7.0	32.0%
total dairy	76.3	24.4	32.0%
meat, poultry, and fish [5]			
red meat	30.4	4.9	16.0%
poultry	17.1	2.7	16.0%
fish and seafood	4.0	0.64	16.0%
total meat	51.5	8.2	16.0%
eggs [6]	7.9	2.5	31.4%
dry beans, peas, and lentils [7]	2.3	0.36	15.9%
tree nuts and peanuts [8]	1.9	0.30	15.9%
caloric sweeteners [9]	38.8	11.9	30.5%
fats and oils [10]	20.3	6.8	33.4%
total			27.0%
	356	96.3	(of total)

<sup>a</sup> The index “*j*” is used as an index for the ten different food categories for the calculations using eqs 2 through 4, S1 through S4, and S8 through S11 (see above and the SI for more information). The term “*f<sub>j</sub>*” is used to denote the fraction of the total production for food category “*j*” that is wasted.

To calculate the energy embedded in wasted food we will calculate the energy required at each of the four food production steps (shown in Table 1 as *i* = 1 to *i* = 4) to produce food in the ten categories (shown in Table 2 as *j* = 1 to *j* = 10) and then use the food loss percentages (*f<sub>j</sub>* from Table 2) to calculate the energy embedded in wasted food. First we define the energy consumed annually for food production (*E<sub>tot</sub>*) in eq 1

$$E_{tot} = \sum_i E_i \quad (1)$$

Equation 1 states that the energy consumed to produce food is equal to the sum of the energy required for each production step (*E<sub>i</sub>*), *i*, shown in Figure S1 and listed in Table 1. For eq 1 the energy intensity (and therefore embedded energy in wasted food) also varies by food category. Consequently we rewrite eq 1 to account for the differences in energy intensity between food categories as eq 2

$$E_{tot} = \sum_i \sum_j E_{ij} \quad (2)$$

In eq 2 the total energy for food production is the sum of the energy required to produce each food category, *j* (listed in Table 2), at each production step, *i*. However, values for *E<sub>ij</sub>* are not available in the literature, and thus they must be deduced. Consequently we replace *E<sub>ij</sub>* with the total energy required for each production step *i* and the relative energy intensity for food category *j* and production step *i*, *A<sub>ij</sub>*, as shown in eq 3

$$E_{tot} = \sum_i \sum_j E_i A_{ij} \quad (3)$$

When we include the fraction of food lost in each category (*f<sub>j</sub>*) in eq 3 we obtain an estimate for the energy embedded in wasted food (*E<sub>loss</sub>*) as shown in eq 4

$$E_{loss} = \sum_i \sum_j E_i A_{ij} f_j \quad (4)$$

In eq 4 *E<sub>i</sub>* and *f<sub>j</sub>* can be determined by normalizing and scaling values published in the literature, as shown in Tables 1 and 2. In this section we will develop reasonable estimates for *A<sub>ij</sub>*, which we will then use to calculate the total energy embedded in wasted food.

We calculate *A<sub>ij</sub>* in three different ways for the different production steps. In agriculture some products are far more energy intensive than others. For instance, the production of animal products requires energy to grow the animal's feed and must account for efficiency losses in the animal when converting feed to edible mass. We use data from Pimentel (30, 31) on the amount of energy necessary to produce a kcal of protein energy for subcategories in eight different food categories (grains, fruits, vegetables, meat, dairy, eggs, dry beans, peas, and lentils, and tree nuts and peanuts), and

**TABLE 3. Energy Required for the Agricultural Production (*i* = 1) of Food Categories for Different Food Categories Was Calculated Using Relative Intensity Factors and the Mass of Agricultural Products before Processing<sup>a</sup>**

food category [index = <i>j</i> ]	weighted average energy intensity by mass ( $\bar{e}_{avg,j}$ ) [kcal/lb]	annual consumption [million tons]	energy for food production [trillion kcal] ( <i>E<sub>ij</sub></i> )	relative energy intensity ( <i>A<sub>ij</sub></i> ) [%]	agriculture energy, by food category ( <i>E<sub>ij</sub></i> ) [trillion BTU]
grains [1]	381	73.8	56.2	5.62	71.4
vegetables [2]	310	68.0	42.2	4.22	53.5
fruit [3]	259	41.0	21.2	2.12	26.9
dairy [4]	2220	41.5	184	18.4	234
meat, poultry, fish [5]	7070	43.3	613	61.3	778
eggs [6]	7840	4.88	76.5	7.64	97.1
dry beans, peas, and lentils [7]	71.8	48.8	7.01	0.70	8.89
tree nuts and peanuts [8]	85.7	1.5	0.26	0.03	0.33
caloric sweeteners [9]	—	—	—	0	0
fats and oils [10]	—	—	—	0	0
total, 2004			1000		1270

<sup>a</sup> The total energy value for agriculture was scaled from the Table 1 value for 2004, the year of this analysis.

**TABLE 4. Energy Required for Transportation ( $i = 2$ ) by Food Category Was Calculated for 2004 Using the Mass-Based Relative Energy Intensity Values**

food category [ $j$ ]	mass of food [million tons]	relative energy intensity ( $A_{2j}$ )	transportation energy, by food category ( $E_{2j}$ ) [trillion BTU]
grains [1]	28.3	0.11	185
vegetables [2]	62.2	0.24	407
fruit [3]	41.2	0.16	270
dairy [4]	41.6	0.16	273
meat, poultry, fish [5]	43.3	0.17	284
eggs [6]	4.9	0.02	32.0
dry beans, peas, and lentils [7]	1.0	0.004	6.5
tree nuts and peanuts [8]	1.5	0.006	9.8
caloric sweeteners [9]	20.9	0.08	137
fats and oils [10]	13.0	0.05	85.4
total, 2004	258		1690

food mass data obtained from the USDA Economic Research Service (9, 32–35) to calculate the relative energy intensity of each category. For this analysis we were only able to locate energy intensity values for seventeen food subcategories in the literature. To calculate the energy intensity of the food categories used in this report we first list all of the subcategories for which we have data and calculate their energy intensities per mass using the Eshel Martin methodology (detailed in the SI) (36), and then we calculate a weighted average of the energy intensities of the subcategories to represent the average energy intensity of the eight food categories. We used this methodology to mitigate skewing of the food category energy intensity by an unrepresentative food subcategory and to calculate representative energy intensity for the entire food category. We use 2004 data for this calculation, thus the results are considered to be for the year 2004. The final relative energy intensity values for agriculture ( $A_{ij}$ ) are summarized in Table 3. A detailed account of our methodology for calculating the relative energy intensity of each food category for the agriculture production step is given in the Supporting Information (SI) that accompanies this work.

The relative energy intensity of each food category for agriculture is calculated from the weighted average of the energy intensity of the food subcategories listed in Table S10 and the mass of each food category consumed annually (listed in Table S11).

It is important to note that the energy intensity values from Pimentel used in this study account for the energy used to produce agricultural inputs to the agriculture sector such as livestock feed from corn. Therefore, to avoid double-counting, we did not include livestock feed in our analysis as it is already accounted for in the energy intensity factors used. Also, throughout this study we consider food to be the primary product of the agriculture sector. See the SI for more details on our full methodology and considerations.

Data for the food categories ‘caloric sweeteners’ and ‘fats and oils’ are not reported in the Pimentel et al. works; these omissions are logical since caloric sweeteners and fats and oils are made from primary agricultural products, which are included in this analysis. We include soy for human consumption (32, 33), corn for processing (35), and sugar crops (34) into the dry beans and vegetable categories, respectively, to account for the missing categories, as a portion of these crops are used to produce fats, oils, and sweeteners.

For food transportation we define  $A_{2j}$  (where  $i = 2$  is for transportation) as the ratio of the mass of a given food category to the total mass of food production. We assume that the energy intensity of food transportation depends on

**TABLE 5. Energy Required for the Processing of Food ( $i = 3$ ) Was Calculated Using Adjusted Mass Based Relative Energy Intensity Values To Account Only for Foods That Undergo Processing before Sale<sup>a</sup>**

food category [ $j$ ]	mass [million tons]	relative energy intensity ( $A_{3j}$ )	food processing energy, by food category ( $E_{3j}$ ) [trillion BTU]
grains [1]	28.3	0.14	155
vegetables [2]	32.5	0.16	178
fruit [3]	22.3	0.11	122
dairy [4]	41.6	0.20	229
meat, poultry, fish [5]	43.3	0.21	238
eggs [6]	4.9	0.02	27
dry beans, peas, and lentils [7]	1.0	0.005	5
tree nuts and peanuts [8]	1.5	0.007	8
caloric sweeteners [9]	20.9	0.10	115
fats and oils [10]	13.0	0.06	72
total, 2004	209.3		1150

<sup>a</sup> These values are scaled to represent 2004 energy consumption.

**TABLE 6. Energy Required for Food Handling ( $i = 4$ ) by Food Category Was Calculated for 2004 Using the Mass Based Relative Energy Intensity Values**

food category [ $j$ ]	mass of food [million tons]	relative energy intensity ( $A_{4j}$ )	food handling energy, by food category ( $E_{4j}$ ) [trillion BTU]
grains [1]	28.3	0.11	426
vegetables [2]	62.2	0.24	935
fruit [3]	41.2	0.16	619
dairy [4]	41.6	0.16	627
meat, poultry, fish [5]	43.3	0.17	652
eggs [6]	4.9	0.02	73
dry beans, peas, and lentils [7]	1.0	0.004	15
tree nuts and peanuts [8]	1.5	0.006	23
caloric sweeteners [9]	20.9	0.08	314
fats and oils [10]	13.0	0.05	196
total, 2004	258		3880

the amount of food that is produced, since food transportation is mass-dependent and measured in ton-miles. The mass of food in Table 4 differs from the masses used to calculate  $A_{ij}$  (shown in Table S10) because it accounts for food in its finished form (as reported in the USDA Food Availability Report for 2004 (9)), rather than in its raw form (for example, sugar cane is classified as a vegetable in Table S10 and as a caloric sweetener in Table 4). The calculation of the relative energy intensity for food transportation by food category is shown in Table 4.

The  $A_{3j}$  ( $i = 3$  is for food processing) term used for the energy consumed in food processing was calculated using mass ratios with the mass of processed fruits and vegetables used in place of the total mass of these two food categories. In the food availability report the USDA separates fruits and vegetables that are processed and those that are sold fresh (9). We expect that fruits and vegetables sold fresh have no or minimal processing. Food processing includes such varied operations as grain milling, canning, slaughtering, and all other modes of food preparation. Nearly all food goes through some form of processing; consequently we used mass ratios for  $A_{ij}$  and only included the mass of fruits and vegetables that the USDA (9) reports as processed. The calculation of

**TABLE 7. Energy Embedded in Wasted Food Was 2010 Trillion BTU in 2004 and 2030 Trillion BTU in 2007<sup>a</sup>**

food category [j]	agriculture [trillion BTU] (i = 1)	transportation [trillion BTU] (i = 2)	food handling [trillion BTU] (i = 3)	food processing [trillion BTU] (i = 4)	total energy, 2004 [trillion BTU]	%wasted	energy lost, 2004 [trillion BTU]	energy lost, 2007 [trillion BTU]
grains [1]	71.4	185	426	155	838	32%	268	271
vegetables [2]	53.5	407	935	178	1580	25.3%	381	379
fruit [3]	26.9	270	619	122	1040	23.4%	234	243
dairy [4]	234	273	627	229	1360	32%	436	441
meat, poultry, fish [5]	778	284	652	238	1950	16%	312	316
eggs [6]	97.1	32.0	73	27	229	31.4%	72.0	72.9
dry beans, peas, and lentils [7]	8.89	6.5	15	5	35.6	15.9%	5.67	5.74
tree nuts and peanuts [8]	0.33	9.8	23	8	40.9	15.9%	6.50	6.58
caloric sweeteners [9]	0	137	314	115	566	30.5%	173	175
fats and oils [10]	0	85.4	196	72	353	33.4%	118	119
<b>total</b>	<b>1270</b>	<b>1690</b>	<b>3880</b>	<b>1150</b>	<b>7980</b>		<b>2010 ± 160</b>	<b>2030 ± 160</b>

<sup>a</sup> Wasted dairy represented the greatest amount of energy waste of any food category.

the relative energy intensity of food processing by food category is in Table 5.

For the food handling step ( $i = 4$ ) we also define  $A_{4j}$  as the percent of total mass as defined for the transportation step (see Table 4 and 6,  $A_{4j} = A_{2j}$ ). The amount of energy required to refrigerate, cook, and package food can be linked to its density and size, thus we expect the percent of total mass to be a reasonable estimate of  $A_{4j}$ .

The relative energy intensity ( $A_{ij}$ ) was combined with the energy required for each food production step ( $E_i$ ) using eq 3 to calculate the energy required for each food category at each production step. These calculations are summarized in Tables 3–6. In these tables the energy for each food production step is converted from 2002 values (given in Table 1) to 2004 values using the ratio of the total energy used in 2004 (100,400 trillion BTU ( $I_8$ )) to the energy use in 2002 (97,900 trillion BTU ( $I_8$ )).

The last columns in Tables 3–6 are combined with the food waste percentages in Table 2 to calculate the embedded energy in wasted food as outlined in eq 4 (see Table 7). Table 2 contains food loss factors for processed fruits and vegetables (16% and 15.8%, respectively), which we use for the fruit and vegetable categories for the food processing step in Table 7 and then added into the total estimate for energy lost due to food waste for the respective food categories.

## Discussion

From this analysis we concluded that the food wasted in the U.S. in 2007 represents approximately  $2030 \pm 160$  trillion BTU (the error for 2004 and 2007 is roughly the same due to rounding) of embedded energy. The wasted energy calculated here is a conservative estimate both because the food waste data are incomplete and outdated and the energy consumption data for food service and sales are incomplete (see the SI). We assign to the energy lost estimate an error of 20% to account for changes in food waste from 1995 and for the assumptions made in arriving at the final energy estimate as we did in the initial estimate for the energy required to produce food consumed in the U.S. In Table 7 the food category that requires the greatest energy to produce is the meat, poultry, and fish category. Nonetheless, the food categories with the greatest embedded energy in their waste are dairy and vegetables. This discrepancy results from the greater proportional waste of dairy and vegetables (32% and 25.3%, respectively (8)) as compared to meat (16% wasted annually (8)) in addition to their high energy requirements.

Despite the fact that the energy loss estimate in this analysis represents a lower bound on the actual value, it

represents a significant amount of lost energy through food waste. The energy discarded in wasted food is more than the energy available from many popular efficiency and energy procurement strategies, such as the annual production of ethanol from grains (37, 38) and annual petroleum available from drilling in the outer continental shelf (39). Consequently, the energy embedded in wasted food represents a substantial target for decreasing energy consumption in the U.S. A decrease in food waste must be accompanied with a retooling of the food supply chain to ensure that the energy consumed during food production does in fact decrease with a decrease in food waste. A study of the economics, feasibility, and policies necessary to achieve energy savings by decreasing food waste would be valuable but is beyond the scope of this work.

Though we were able to estimate the energy required to produce the food consumed in the U.S. and the energy embedded in wasted food, the data used were incomplete and out of date, likely representing a lower bound on the actual value. Further research is necessary to obtain more recent and accurate accounts of the energy used in fisheries, aquaculture, food packaging, disposal, and commercial food preparation. An updated and comprehensive study of food waste in the U.S. food system accounting for waste in the fishing industry, on the farm, and during food processing is also necessary.

## Supporting Information Available

Complete methodology and calculation of the energy required to produce food for domestic consumption and for the relative energy intensity values for the agriculture production step. This material is available free of charge via the Internet at <http://pubs.acs.org>.

## Literature Cited

- (1) FAO. *The State of Food and Agriculture*; United Nations Food and Agriculture Organization: 2008.
- (2) Liebreich, M.; Rodriguez, R.; Boyle, H.; Ramos, C. *Research Note, Insight Services: Biofuels*; New Energy Finance: 2008.
- (3) USDA. *Trends in US Agriculture*; USDA National Agriculture Statistics Service: 2006.
- (4) EPA. *Demographics*; U.S. Environmental Protection Agency: 2007.
- (5) Heller, M. C.; Keoleian, G. A. *Life Cycle-Based Sustainability Indicators for Assessment of the U.S. Food System*; University of Michigan: Ann Arbor, 2000.
- (6) Pimentel, D.; Pimentel, M. Sustainability of meat-based and plant-based diets and the environment. *Am. J. Clin. Nutr.* **2003**, *78* (suppl), 660S–3S.
- (7) Canning, P.; Charles, A.; Huang, S.; Polenske, K. R.; Waters, A. *Energy Use in the U.S. Food System*; U.S. Department of Agriculture, Economic Research Service: 2010.

- (8) Kantor, L. S.; Lipton, K. Estimating and addressing America's food losses. *Food Rev.* **1997**, *20* (1), 2.
- (9) USDA. *Food Availability*; U.S. Department of Agriculture: March 11, 2009.
- (10) Elitzak, H. *Food Cost Review, 1950–97*; Report No.: Agricultural Economic Report No. 780; U.S. Department of Agriculture, Economic Research Service: 1999.
- (11) Blisard, N.; Stewart, H. *Food Spending by American Households, 2003–04, Summary*; U.S. Department of Agriculture, Economic Research Service: 2007.
- (12) USCB. *U.S. Population Projections*; U.S. Census Bureau: 2008.
- (13) Pimentel, D.; Williamson, S.; Alexander, C.; Gonzalez-Pagan, O.; Kontak, C.; Mulkey, S. Reducing Energy Inputs in the US Food System. *Hum. Ecol.* **2008**, *36* (4), 459–71.
- (14) Steinhart, J. S.; Steinhart, C. E. Energy Use in the U.S. Food System. *Science* **1974**, *184* (4134), 307–16.
- (15) Tyedmers, P. H.; Watson, R.; Pauly, D. Fueling Global Fishing Fleets. *AMBIO: A Journal of the Human Environment* **2005**, *34* (8), 635–8.
- (16) Economist.com. No more fish in the sea. *The Economist*, March 2, 2009.
- (17) ERS. *Food Availability*; U.S. Department of Agriculture: March 11, 2009.
- (18) EIA. *Annual Energy Review 2007*; Energy Information Administration: 2007.
- (19) NOAA. Aquaculture in the United States. 2009. Available at <http://aquaculture.noaa.gov/us/welcome.html> (accessed February 6, 2009).
- (20) ERS. *Aquaculture Data: Vol. and value of U.S. imports of selected fish and shellfish products*; U.S. Department of Agriculture: 2009.
- (21) BTS. *2002 Commodity Flow Survey*; U.S. Census Bureau and Bureau of Transportation Statistics: 2002.
- (22) EIA. *Energy Efficiency Report: The Transportation Sector*; Energy Information Administration: 1999.
- (23) CBO. *Energy Use in Freight Transportation*; Congressional Budget Office: 1982.
- (24) FHWA. *Energy Intensities of Domestic Freight Modes*; U.S. Department of Transportation-Federal Highway Administration: 2006.
- (25) Weber, C. L.; Matthews, H. S. Food-Miles and the Relative Climate Impacts of Food Choices in the United States. *Environ. Sci. Technol.* **2008**, *42* (10), 3508–13.
- (26) EIA. *Commercial Building Energy Consumption Survey 2003*; Energy Information Administration: 2003.
- (27) EIA. *Residential Energy Consumption Survey 2001*; Energy Information Administration: 2001.
- (28) EPA. *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2006*; U.S. Environmental Protection Agency: 2006.
- (29) Stuart, T. *Waste: Uncovering the Global Food Scandal*, 1st American ed.; W.W. Norton & Co.: New York, 2009.
- (30) Pimentel, D. *Food, Energy, and Society*; Taylor & Francis Ltd.: Hoboken, 2007; 402p.
- (31) Pimentel, D. *Impacts of Organic Farming on the Efficiency of Energy Use in Agriculture*; The Organic Center: 2006.
- (32) USDA. *Oil Crops Yearbook*; Economic Research Service, U.S. Department of Agriculture: 2009.
- (33) *Economic Impacts of Biodiesel Production on the Soybean Sector*; United Soybean Board: 2009.
- (34) ERS. *Sugar and Sweeteners Yearbook Tables*; U.S. Department of Agriculture Economic Research Service: 2009.
- (35) ERS. *Feed Grains Database*; U.S. Department of Agriculture Economic Research Service: 2009.
- (36) Eshel, G.; Martin, P. A. Diet, Energy, and Global Warming. *Earth Interact.* **2006**, *10* (1), 1–17.
- (37) RFA. Ethanol Industry Statistics. Available at <http://www.ethanolrfa.org/industry/statistics/> (accessed June 19, 2009).
- (38) EIA. Ethanol. Available at <http://www.eia.doe.gov/oiaf/ethanol3.html> (accessed June 18, 2009).
- (39) EIA. *Impacts of Increased Access to Oil and Natural Gas Resources in the Lower 48 Federal Outer Continental Shelf*; Energy Information Administration: 2007.

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