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# 바이오에너지로의 전환을 위한 캘리포니아 식품가공공장 오·폐수 특성 조사 및 경제성 분석

김대현

# Survey and Economic Analysis of Food Industry Residues for Biomass-to-energy Conversion in Merced and Stanislaus Counties, California, USA

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**Abstract**

This research expands investigations into the biomass resource potential associated with California's food processing industry by surveying industries within a two county region in the San Joaquin Valley, California, USA. A previous survey conducted in 2005 for the Sacramento Municipal Utility District (SMUD) quantified residue and waste generation from food processors and food preparation businesses in the Sacramento region. The present survey investigates residue and waste streams from food processors located in Merced and Stanislaus Counties. Sixty food processors were identified to participate in the survey, of which 49 responded (82%) and data were acquired for 38 (63%) (6 facilities closed or moved, 8 decided not to participate). Within the two counties, total annual waste among survey respondents amounted to 24,044 dry tons of high moisture (≥60%) food residuals, 5,358 dry tons of low moisture (<60%) food residuals; and 23.7 million $m^3$ of wastewater containing 38,814 tons of biochemical oxygen demand ($BOD_5$). The total potential electric power generation from these food residues was estimated at approximately 7 $MW_e$. Total solid waste resource included in the survey response was estimated at about 10% of statewide residue generation for processors falling within the Standard Industrial Classification (SIC) System Major Group 20 (Food and Kindred Products) categories.

**Keywords** : Food industry residues, Wastewater, Solid waste, Biomass, Energy conversion

## 1. Introduction

California's food processing industry generates annual revenues in excess of $50 billion and is the third largest industrial energy user in the state (Amon et al., 2008). The industry also produces organic residues with potential for use in energy conversion for fuels and electricity. As a prelude to a larger statewide analysis, a two county survey was conducted to evaluate the potential for biomass-to -energy conversion using residual food streams generated from food processors. This investigation complements a previous Sacramento region study (Matteson et al., 2005) to include food processors in Stanislaus and Merced Counties, California.

The principal objectives of this study was to identify types and quantify annual amounts of residues and wastes generated by food processing industries in Merced and Stanislaus counties of California and to estimate electric energy conversion potentials from identified residues and wastes. The survey identified the flows of both solid

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residues and wastewater generated from major food processing operations and also investigated current waste and wastewater management practices. Based on survey responses, estimates of potential electricity generation were made from amounts of high and low moisture solid wastes and wastewater. Costs of energy were also estimated for average facility sizes resulting from the survey, including combined heat and power and potentials for peak power generation.

## 2. Materials and Methods

### A. Survey Methods

Selected high volume food processing facilities were identified through records of the California League of Food Processors, the California Energy Commission, the Standard Industrial Classification (SIC) System of the U.S. Department of Labor, and local offices of UC Cooperative Extension. A total of sixty businesses falling generally within the SIC Major Group 20 (Food and Kindred Products) were identified for potential participation in a survey of residue and waste generation and current utilization or disposal practices. Individual businesses were contacted by email, phone, and regular mail and invited to participate in the survey. Those choosing to participate responded to the survey through email, phone, mail, and/or direct interview. To obtain waste-related data from industries which did not respond to the survey request, information was acquired where possible from the associated Regional Water Quality Control Boards in Rancho Cordova and Fresno, California. Local wastewater treatment facilities located in Merced County (Atwater, Gustine, Hilmar, Livingston, Los Banos, City of Merced, Planada) and Stanislaus County (Ceres, Hughson, Modesto, Newman, Oakdale, Patterson, Riverbank, Turlock) were also contacted to collect wastewater-related data for discharges from food industries in those areas. County Agricultural Commissioners, UC Cooperative Extension staff in each county, and staff of the California Integrated Waste Management Board were also consulted to obtain relevant facility information.

A survey form was prepared in consultation with the California League of Food Processors. The survey was first tested in draft form through direct interview with two of the major food processors in the counties, and then by telephone with a third. Surveys were then emailed and mailed to the remaining 57 companies with a request to participate. Mail surveys were followed up with telephone calls to confirm participation, answer questions regarding the survey, or to conduct the survey over the phone. Of the 60 companies identified, 35 (58%) companies chose to participate and completed the survey instrument (Table 1), 8 (13%) companies responded but chose not to participate, 6 (10%) companies were no longer in business in the region, and another 11 (18%) did not respond and could not be contacted otherwise. Information on 3 of the latter companies (included for convenience in the following as respondents) was obtained through records held by the Regional Water Quality Control Boards, bringing the total number of companies for which data were obtained to 38 (63%).

A search of SIC 20 returned 1,423 facilities in California, of which 67 were located in Merced and Stanislaus Counties (Table 2). These were separately identified by type with 8 facilities outside the direct food processing industry, leaving 59 facilities within the survey categories. The survey identified a number of other facilities, so not all companies surveyed are included in the SIC 20 classification. Of the 38 operations surveyed, 23 (61%) were listed in the SIC 20 classification (Table 2).

The survey requested information on the following :

- primary products produced at the food industry facility or facilities
- co-products produced
- production season
- electricity and natural gas energy demand over the previous three years
- other energy sources
- water demand
- wastewater discharge
- wastewater composition and biological oxygen demand (BOD)
- solid wastes and residues including annual quantities and moisture content
- waste handling and disposal practices
- cost of handling and disposal
- other uses for residues including on-site or other energy conversion
- waste or residue properties

Results were tabulated and sorted according to food

**Table 1** Survey response rates

| | | | | |
|---|---|---|---|---|
| Responded or data obtained otherwise | Responded | Surveyed | 35 | 58% |
| | | Management decided not to participate | 8 | 13% |
| | | Changed, moved, or closed business | 6 | 10% |
| | Subtotal | | 49 | 82% |
| | No response | From regional water quality control boards and local wastewater treatment plants | 3 | 5% |
| Subtotal | | | 52 | 87% |
| Did not respond | | | 8 | 13% |
| Total | | | 60 | 100% |

**Table 2** Number of food processing facilities surveyed and identified in SIC 20

| Community type | SIC 20 | | | Surveyed | | | Surveyed included in SIC 20 | | |
|---|---|---|---|---|---|---|---|---|---|
| | M* | S* | Total | M | S | Total | M | S | Total |
| Fruit and vegetable | 6 | 9 | 15 | 6 | 5 | 11 | 2 | 2 | 4 |
| Dairy products** | 6 | 10 | 16 | 4 | 5 | 9 | 4 | 4 | 8 |
| Meat | 4 | 8 | 12 | 2 | 5 | 7 | 2 | 3 | 5 |
| Cannery | 3 | 2 | 5 | 1 | 3 | 4 | 0 | 2 | 2 |
| Winery and beverage | 2 | 5 | 7 | 2 | 1 | 3 | 1 | 1 | 2 |
| Bakery and snacks | 1 | 3 | 4 | 0 | 4 | 4 | 0 | 2 | 2 |
| Other | | 8 | 8 | | | | | | 0 |
| Total | 22 | 45 | 67 | 15 | 23 | 38 | 9 | 14 | 23 |

*M = Merced County, S = Stanislaus County. **Does not include dairy farms.

production or processing activity. Solid wastes and residues were classified by moisture content for the purposes of estimating electricity generation potentials. Residues with moisture at or above 60% wet basis were classified as high moisture (HM) solid waste and biochemical energy convert-sion approaches (e.g. anaerobic digestion with combustion of biogas) were assumed for estimating energy potential. Residues with moisture below 60% were classified as low moisture (LM) solid waste and assumed to be converted via thermochemical methods (e.g. combustion) although in some cases feedstock drying might still be needed prior to conversion.

## B. Food industry locations

Most food processors surveyed were located along the Interstate 5 and U.S. 99 highway corridors, and grouped together in or near cities, particularly Modesto, Turlock, and Los Banos (Fig. 1). Survey results were compiled and categorized by type of food processing industry. Within the two counties, the 38 companies for which data were obtained included 11 fruit and vegetable packing and freezing operations, 9 dairy products and cheese operations exclusive of dairy farms, 7 meat processing facilities, 4 canning operations, 3 winery and beverage operations, and 4 bakery and snack preparation facilities (Table 2).

## C. Potential electricity calculations

Estimates were made of potential electricity generation from the quantities of residues produced, ignoring any economic or regulatory limitations. The generation was classified into high moisture solid waste (dry tons $y^{-1}$), low moisture solid waste (dry tons $y^{-1}$) and wastewater (gallons $y^{-1}$) and BOD5 sources. Anaerobic digestion was assumed as the basis for high moisture solid waste and wastewater conversion into energy, and combustion for low moisture solid waste.

The annual electricity generated from high moisture materials using anaerobic digestion was estimated as:

$$E_{AD,i} = \frac{1}{3.6} q_i f_{vs} b_i g c_{CH4} Q_{CH4} \eta_e \qquad (1)$$

where,

$E_{AD,i}$ = annual electricity generated (MWh $y^{-1}$)

$q_i$ = annual available resource (total solids) of biomass

type $i$ (Mg $y^{-1}$ dry matter)
$f_s$ = fraction of volatile solids in total solids, VS:TS
$b_i$ = biodegradability fraction for volatile solids of biomass type $i$
$g$ = biogas yield ($m^3$ $kg^{-1}$ volatile solids destroyed)
$C_{CH4}$ = volume concentration of methane in biogas ($m^3$ $m^{-3}$)
$Q_{CH4}$ = heating value of methane (MJ $m^{-3}$)
$\eta_e$ = engine-generator efficiency on biogas

For thermochemical-based power generation, the annual electricity generated with low moisture materials was estimated as:

$$E_{TC,i} = \frac{1}{3.6} q_i Q_i \eta_{TC} \qquad (2)$$

where,
$E_{TC,i}$ = annual electricity generated (MWh $y^{-1}$)
$Qi$ = heating value of biomass type $i$ (MJ $kg^{-1}$ dry matter)
$\eta_{TC}$ = overall thermochemical conversion efficiency to electricity

Equation (2) constitutes an overestimate of power potential if where needed, feedstock drying is accomplished with process energy other than solar energy or waste heat. The annual potential energy from digestion of wastewater was estimated as:

$$E_w = \frac{1}{3.6\text{x}10^9} V_w C_{BOD} M_{CH4} Q_{CH4} \eta_e \qquad (3)$$

where,
$E_w$ = annual electric energy (MWh $y^{-1}$)
$V_w$ = volumetric wastewater available (L $y^{-1}$)
$C_{BOD}$ = biological oxygen demand (mg $L^{-1}$)
$M_{CH4}$ = theoretical methane yield from BOD (m3 $kg^{-1}$)

For materials converted via anaerobic digestion, the fraction of volatile solids in total solids (VS:TS) used for equation (1) was assumed to be 0.8, biodegradability was 0.67, biogas yield was 0.75 $m^3$ $kg^{-1}$, methane concentration of biogas was 65%, and the engine-generator efficiency was 30%. These assumptions for anaerobic digestion with wastewater were estimated from data of Matteson and Jenkins (2007). They presented potential for power generation from food and processing residues which are the same materials treated by this study. The assumptions of VS:TS, VS biodegradability, biogas yield and methane concentration combine to give a methane yield of 0.261 $m^3$ $kg^{-1}$ VS destroyed. For comparison, the theoretical methane yield used in equation (3) is 0.351 $m^3$ $kg^{-1}$ BOD. The heating value of methane is 36.3 MJ $m^{-3}$ at standard conditions. In thermochemical

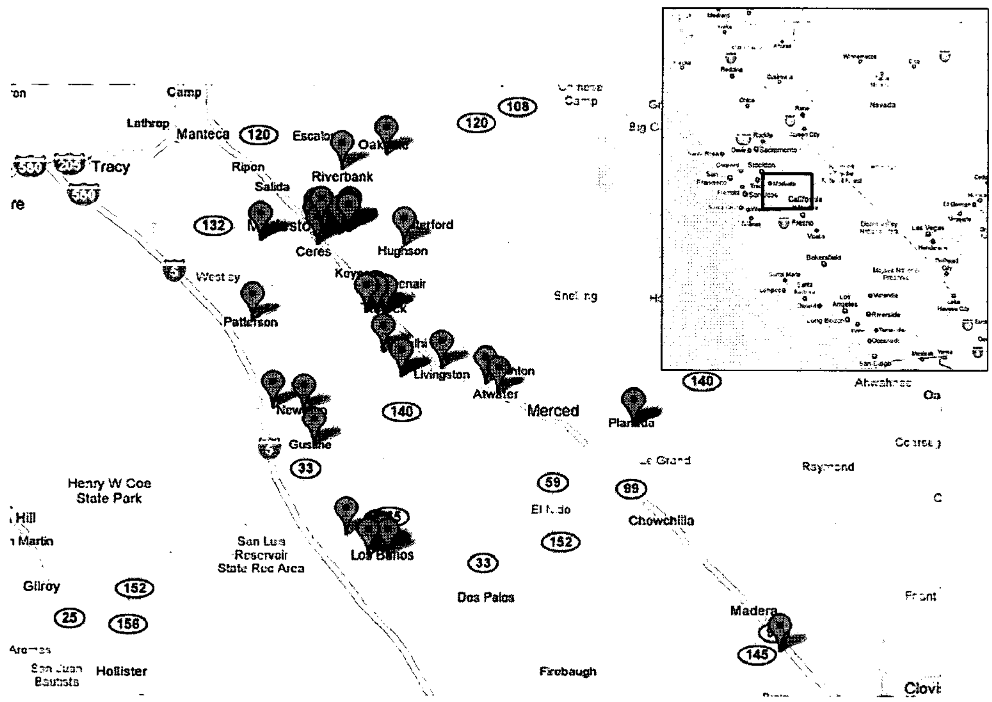



**Fig. 1** Respondent locations in Merced and Stanislaus counties. Inset: location of survey area within California (maps courtesy of Google Maps).

conversion (equation (2)), the conversion efficiency was assumed to be 25% based on new biomass direct combustion units and the heating value of food waste was assumed to be 20 MJ kg-1 dry basis for this study based on a typical range between 18 and 25 MJ $kg^{-1}$ for food waste among municipal solid waste (MSW) category (Liu and Lipták, 2000; Rao et al., 2004).

## 3. Results and Discussions

### A. Food industry residue production

Total facility primary production capacities varied from 150 to more than a million wet tons per year, with annual energy usage ranging from 10,000 to 20 million kWh for electricity and 2,800 to 70,800 $m^3$ per year for natural gas, although complete data were not supplied by all respondents. Some processors operated essentially year round (300 days or more), but fruit and vegetable industries typically operated only for several months, generally during the summer or fall production season.

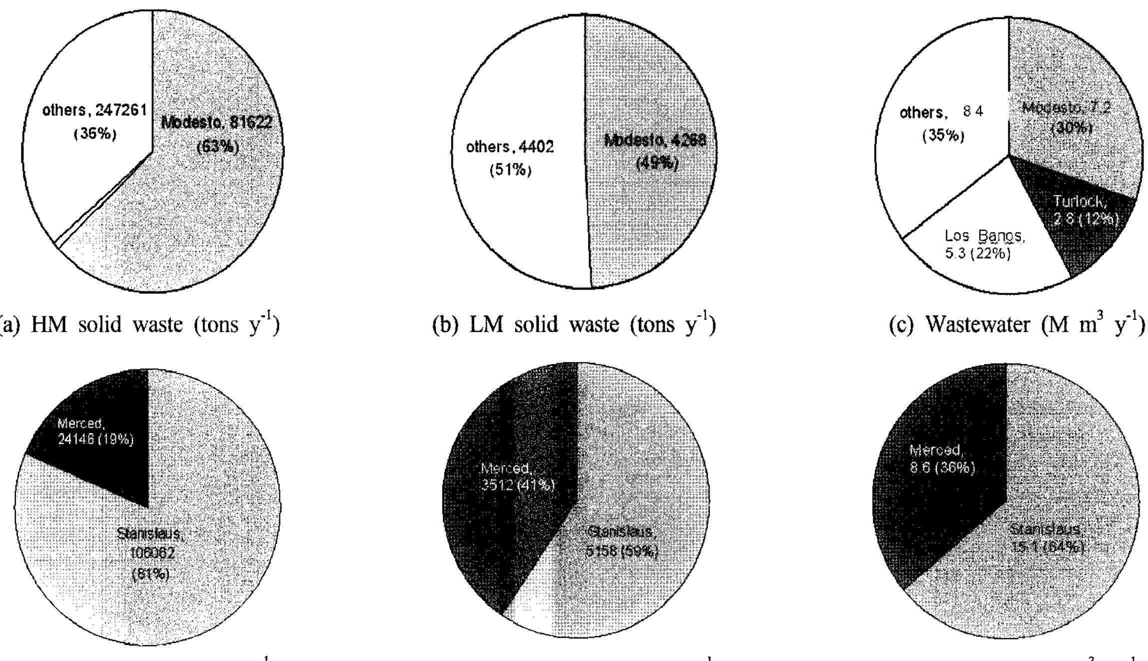
Ten of the food processors were located in Modesto (Stanislaus County) and generated 81,622 tons of HM solid waste, 4,268 tons of LM solid waste, and 7.2 million $m^3$ of wastewater per year, constituting 63%, 49%, and 30% of the total amounts identified among all respondents, respectively (Fig. 2). Seven processors were located in Los Banos (Merced County), with another six in Turlock (Stanislaus County).

Of the respondents, 23 (60%) were located in Stanislaus County, accounting for 106,062 wet tons per year of HM solid waste, or 81% of the total among the two counties (Fig. 2). Stanislaus also accounted for 5,158 tons per year of LM solid waste (59%) and 15.1 million $m^3$ of wastewater (64%).

Annual estimated quantities of HM and LM solid waste and wastewater produced within each processing category are shown in Tables 3 - 5. The majority of high moisture waste was generated from fruit and vegetable operations and canneries, whereas low moisture wastes were principally from wineries and bakeries (Tables 3 and 4). Average BOD of wastewater was highest from dairy products and cheese producers (Table 5). The large variation in processing capacity results in high standard deviation across category for some types of processing operations (e.g. fruits and vegetables).

### B. Comparison with statewide estimates

Estimates have recently been made of amounts of food industry residues and solid wastes generated in California (Matteson and Jenkins, 2007). For non-meat related food




(a) HM solid waste (tons $y^{-1}$) (b) LM solid waste (tons $y^{-1}$) (c) Wastewater (M $m^3$ $y^{-1}$)

(d) HM solid waste (tons $yr^{-1}$) (e) LM solid waste (tons $yr^{-1}$) (f) Wastewater (M $m^3$ $yr^{-1}$)

**Fig. 2** Generation of food industry wastes and residues by city (a-c) and county (d-f). HM refers to high moisture (≥60% wet basis) material, LM refers to low moisture (<60%) material. M $m^3$ = million $m^3$.

**Table 3** High moisture (≥60%) solid waste by processing category

| Community type | No. of processors | Moisture** (% wet basis) | Total (wet tons $y^{-1}$) | Facility Average (wet tons $y^{-1}$) | Facility Standard Deviation (wet tons $y^{-1}$) |
|---|---|---|---|---|---|
| Fruits and vegetables | 6 | 75 | 36,065 | 6,011 | 9,199 |
| Dairy products* | - | - | - | - | - |
| Meat | 3 | 76 | 525 | 175 | 109 |
| Cannery | 3 | 88 | 72,000 | 24,000 | 7,937 |
| Winery and beverage | 2 | 73 | 14,343 | 7,172 | 919 |
| Bakery and snacks | 3 | 62 | 7,275 | 2,425 | 2046 |
| Total | 17 | 82*** | 130,208 | 7,234 | 9,946 |

*Dairy products operations included in wastewater. **Facility average. ***Total residue weighted average for all respondents.

**Table 4** Low moisture (<60%) solid waste by processing category

| Community type | No. of processors | Moisture** (% wet basis) | Total (wet tons y-1) |
|---|---|---|---|
| Fruits and vegetables | 1 | 35 | 890 |
| Dairy products | - | - | - |
| Meat | - | - | - |
| Cannery | - | - | - |
| Winery and beverage | 2 | 35 | 4,810 (3,512 & 1,298)* |
| Bakery and snacks | 2 | 38 | 2,970 (870 & 2,100) * |
| Total | 5 | 38*** | 8,670 |

*Total and amount generated by individual food processors (n=2). **Facility average. ***Total residue weighted average for all respondents.

**Table 5** Wastewater flows and BOD by processing category

| Community type | No. of processors | Facility Average BOD (mg $L^{-1}$) (stdev) | Total Wastewater (M $m^3$ $y^{-1}$)* (BOD tons $y^{-1}$) | Facility Average Wastewater (M $m^3$ $y^{-1}$)* | Facility Standard Deviation (M $m^3$ $y^{-1}$)* |
|---|---|---|---|---|---|
| Fruits and vegetables | 11 | 1,062 (500) | 8.89 (9,370) | 0.81 | 1.08 |
| Dairy products | 9 | 2,202 (1116) | 1.97 (5,728) | 0.22 | 0.29 |
| Meat | 7 | 1,793 (1170) | 3.13 (9,539) | 0.45 | 0.62 |
| Cannery | 4 | 1,399 (1773) | 5.51 (8,131) | 1.38 | 0.64 |
| Winery and beverage | 3 | 1,300 (427) | 2.76 (4,187) | 0.92 | 0.43 |
| Bakery and snacks | 4 | 1,404 (555) | 1.43 (1,859) | 0.36 | 0.41 |
| Total | 38 | 1,557** (1,022) | 23.70 (38,814) | 0.62 | 0.76 |

*M $m^3$ = million $m^3$. **Facility global average. Total wastewater weighted average BODfor all respondents = 1,486 mg $L^{-1}$.

**Table 6** Total food processing solid waste* insurvey compared with statewide estimates

| Commodity type | Survey (dry tons $y^{-1}$) | Survey/State (%) | California (dry tons $y^{-1}$) |
|---|---|---|---|
| Food | 22,346 | 23.8 | 93,716** |
| Meat | 129 | 0.2 | 71,665 |
| Wine | 6,928 | 5.2 | 134,509 |
| Total | 29,402 | 9.8 | 299,890** |

*excludes solids in wastewater. **additional 500,000 tons $y^{-1}$ in shells and pits.

processing, the statewide total solid waste generation, excluding nut shells and fruit pits, was roughly 94,000 tons $y^{-1}$ (85,000 Mg $y^{-1}$) dry weight. Wineries contributed another 134,000 tons y-1, while meat processing added about 72,000 tons $y^{-1}$ for a total approaching 300,000 dry tons $y^{-1}$ (Table 6). Quantities of nut shells and fruit pits amount to about 500,000 tons $y^{-1}$ across the state, although these agricultural processors were not specifically included in the survey.

Overall, the survey responses constitute about 10% of the estimated statewide total, but the distribution within the food, meat, and wine categories is not uniform, with a higher representation within food commodities other than meat, and a low representation among meat processors. Largely this appears to be due to the type of industries located within the region targeted for the survey, but with a 60% response rate the total processing residue in the two counties was not directly quantified by the survey.

## C. Potential electricity from food industry residues

Tables 7 through 9 list the estimated annual electricity generation (energy and capacity) for high moisture waste, low moisture waste, and wastewater from the survey respondents. The capacity (kW) is based on 100% capacity factor and so is lower than any potential installed capacity for the same energy conversion when accounting for scheduled maintenance and seasonal operation. For facilities operating only several months out of the year, capacities would be

**Table 7** Annual electricity potential for high moisture solid waste (survey respondents)

| Community type | No. of processors | Potential electrical energy (MWh $y^{-1}$) | Potential capacity* (kW) |
|---|---|---|---|
| Fruits and vegetables | 6 | 6,132 | 700 |
| Dairy | - | - | - |
| Meat | 3 | 92 | 11 |
| Cannery | 3 | 6,131 | 700 |
| Winery and beverage | 2 | 2,805 | 320 |
| Bakery and snacks | 3 | 2,081 | 238 |
| Total | 17 | 17,241 | 1,969 |

*at 100% capacity factor.

**Table 8** Annual electricity potential for low moisture solid waste (survey respondents)

| Community type | No. of processors | Potential electrical energy (MWh $y^{-1}$) | Potential capacity* (kW) |
|---|---|---|---|
| Fruits and vegetables | 1 | 729 | 83 |
| Dairy | - | - | - |
| Meat | - | - | - |
| Cannery | - | - | - |
| Winery and beverage | 2 | 3,800 | 434 |
| Bakery and snacks | 2 | 2,223 | 254 |
| Total | 5 | 6,752 | 771 |

*at 100% capacity factor.

**Table 9** Annual electricity potential for wastewater (survey respondents)

| Community type | No. of processors | Potential electrical energy (MWh y-1) | Potential capacity* (kW) |
|---|---|---|---|
| Fruits and vegetables | 11 | 9,026 | 1,030 |
| Dairy | 9 | 5,517 | 630 |
| Meat | 7 | 9,188 | 1,049 |
| Cannery | 4 | 7,832 | 894 |
| Winery and beverage | 3 | 4,033 | 460 |
| Bakery and snacks | 4 | 1,790 | 204 |
| Total | 38 | 37,386 | 4,267 |

*at 100% capacity factor.

**Table 10** Waste treatment methods used by survey respondents

| Wastewater | | No. of processors | % |
|---|---|---|---|
| | Discharged to wastewater treatment plant | 31 | 52 |
| | Used as irrigation water at land application sites | 6 | 10 |
| | Other treatment (aeration pond) | 1 | 2 |
| Subtotal | | 38 | 63* |
| Solid waste | | No. of processors | |
| | Landfilled | 13 | 22 |
| | Used as cattle feed, compost, etc. | 3 | 5 |
| | Other treatment (rendering, etc.) | 6 | 10 |
| Subtotal | | 22 | 37 |
| Total | | 60 | 100 |

*may not sum due to rounding.

significantly greater, but annual capacity factors would be substantially less unless facilities imported feedstock to sustain operations throughout the year. Potential power from high moisture waste produced by fruit and vegetable processors and canneries was estimated as 1,400 kW, or 71% of the survey total for this category (Table 7). For low moisture residues, most of the potential was in the winery and bakery processing categories (Table 8). The potential is more evenly distributed for wastewater (Table 9), partly due to the more comprehensive data obtained.

Waste treatment and disposal methods currently used by the respondents are shown in Table 10. Wastewater was mostly discharged to wastewater treatment plants with some disposed of by land application or used as irrigation water. The majority (59%) of solid waste was landfilled, but other uses included animal feed, compost, or rendering.

## D. Economic assessment of energy conversion

The economics associated with energy generated from food residues depends on residue types and production sites. Levelized cost of electricity (COE) from biomass combustion power plants at net efficiencies of 20 - 25% are in the range of $0.05 - 0.09/kWh for fuel costs of $20/ton and $0.04 - 0.08/kWh for anaerobic digestion systems and landfill-gas-to-energy facilities with revenue from tipping (disposal) fees (Jenkins, 2005; Williams, 2005; Rapport, 2008).

Low moisture solid waste constituted a small resource for facilities participating in the survey, although regionally when nut and other agricultural processors are included the potential is larger and feasibility studies for power generation systems based on thermochemical approaches are better justified. Solid waste with high moisture contents and wastewater could be combined as digester feedstock, and could also be considered as co-digestion feedstock for dairy manure or public wastewater treatment digesters. The cost of generating electricity from organic solid waste was recently estimated for a two-stage digestion system operating with heat recovery, returning an internal rate of return (IRR) of 12% when electricity was sold at $0.067/kWh. Costs of energy recovery from wastewater treatment using anaerobic digesters has also recently been estimated for a range of plant sizes and combined heat and power (CHP) technologies (Eastern Research Group, Inc. and Energy and Environmental Analysis, Inc., 2007). This latter study generally assumed that individual CHP systems would not be feasible for municipal wastewater flows below 6.9 million $m^3$ $y^{-1}$, but the analyses are based on flows with relatively low organic loadings, typically around 150 mg BOD $L^{-1}$.

The study for USEPA evaluated costs of power generation for three sizes and technologies under three different conditions: 1) recovered heat replaces biogas-fueled boilers for digester heating, 2) excess heat recovery replaces natural gas used elsewhere on site, and 3) recovered heat replaces all natural gas usage on site. CHP system types analyzed included a 126 kW microturbine, 300 kW fuel cell, and 1,060 kW reciprocating internal combustion engine (ICE), with installed capital costs of $4,484, $7,426, and $2,039/kW capacity, respectively. Net power costs for a natural gas price reflecting a heat value of $0.024/kWh ($7/MMBtu) ranged from $0.030 – 0.065/kWh for the microturbine system, $0.091 – 0.102/kWh for the fuel cell, and $0.001 - 0.038/kWh for the ICE. Fuel cell costs were high partly because of the need to buy natural gas for digester heating due to the higher electrical efficiency of the device.

Using assumptions similar to the USEPA study with a generating capacity (130 kW net) derived from the average wastewater strength in the survey (Table 5), the levelized cost of electricity (COE) with a CHP system displacing natural gas at $0.024/kWh is $0.023/kWh. The rest of the factors relating the economic analysis are assumed as below (Table 11).

**Table 11** Influencing factorson the economic assessment and their assumptions

| Factors | Assumptions |
|---|---|
| Capital cost | $4,484/kW |
| Debt ratio | 75% |
| Debt cost | 7.5% $y^{-1}$ |
| IRR | 15% |
| Economic life | 20 y |
| Tax credit | $0.01/kWh |
| Operating and maintenance cost | $0.022/kWh |
| Heat sales price | $0.024/kWh |
| Capacity factor | 85% |
| Net efficiency | 26.1% |

For this calculation, Energy Cost Calculator provided by The California Biomass Collaborative was used (http://biomass.ucdavis.edu/materials/calculator/EconCalculator_GenericCHP.xls). With no accounting of heat benefits, the COE increases to $0.063/kWh, and without heat or tax credits, to $0.066/kWh. The COE is strongly sensitive to changes in capacity factor, net efficiency, debt ratio, capital cost, and heat price (Fig. 3), and most prominently to reductions in capacity factor which helps explain why systems of this type have not been more widely installed on processing facilities operating for only a few months of the year. For a facility operating only three months (capacity factor of 25%) and with assumptions otherwise equal to those of the base case described above including natural gas offset, the COE increases to $0.181/kWh (2008 constant dollars). However, for facilities operating much of the year, the COE may be below current market price referents (MPR) for the state's renewable portfolio standard (RPS). Carbon credits, which might improve economic feasibility, have not been included in these analyses, but nor has the potentially higher cost of meeting air quality permit requirements, especially for NOx, although general permitting costs were included in the USEPA analysis.

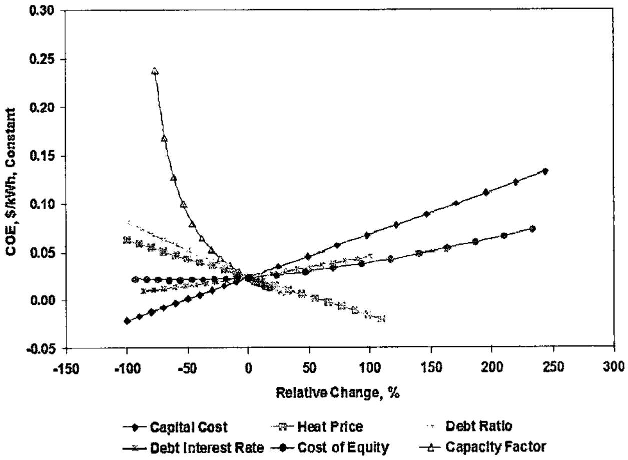



**Fig. 3** Sensitivity to economic and technical performance factors of cost of electricity (2008 constant dollars) from wastewater digestion (net generating capacity = 130 kW, power/heat = 0.6, O&M = 0.022/kWh, economic life = 20 years. Base values: capital cost = $4,484/kW installed, heat sales price = $0.024/kWh ($7/MMBtu), 75% debt ratio, 7.5% $y^{-1}$ debtinterest rate, 15% IRR, 26.1% net efficiency, 85% capacity factor).

With high summertime peak power prices charged by utilities, and newly established high peak period feed-in tariffs, greater incentive exists for managing on-site power generation systems for on-peak operation, possibly through the inclusion of a gas holder or other energy storage. For the same average BOD and wastewater flow as determined in the survey, a power system operating six hours per day on-peak for three months (6.25% annual capacity factor) would support a design capacity of 1,800 kW. If adding gas storage doubled the cost of the digestion system and total system cost increased to the same value ($2,039/kW) as that assumed in the USEPA study at similar capacity, the COE is $0.254/kWh. This may be below peak retail prices for some processors, but is still higher than the summertime peak feed-in tariff for the local utility (Pacific Gas & Electric Co.) in the two county region, currently $0.18/kWh. The COE is below the summertime peak feed-in tariff price of $0.31/kWh offered by Southern California Edison Co.. The analysis suffers from imbalance in heat supply for the digester when the power plant (e.g. ICE) is not operating for systems needing supplemental heat to maintain gas production, especially at night during off-peak hours, so additional cost might be required for thermal storage to continue digester heating and meet other continuous thermal loads. The potential to operate on-peak to offset high utility power prices may be of sufficient interest for more detailed site analyses. Future carbon credits may provide additional incentive for more detailed investigations of this and other types of operation as well.

Other types of energy recovery from food processing wastes include production of biofuels and combining individual waste streams to supply larger conversion facilities taking advantage of economies of scale in capital and operating costs. Additional site analyses and feasibility studies are needed to evaluate these potentials.

## 4. Conclusions

Results from the 38 food processing facilities participating in the Merced and Stanislaus County survey yield aggregate quantities of high and low moisture solid waste and residues and wastewater equivalent to a total electric power generation potential of approximately 7 MW, most of which (4 MW) is associated with wastewater treatment. Average strength of wastewater for all survey respondents was 1,557 mg BOD $L^{-1}$, with a facility average production quantity of 165 million gallons per year. A total of 29,402 dry tons per year of solid waste were generated by these facilities, with greater than 80% of it at a high moisture content averaging 82% wet basis. Another 38,814 tons per year of BOD were associated with 6 billion gallons of wastewater.

The 38 facilities surveyed or for which data were otherwise obtained (3 facilities) constitute 63% of the original 60 facilities identified within the food processing category in the two counties. Survey responses were not always complete, and more comprehensive data were obtained on wastewater flows and quality than on solid wastes. Wastewater data could be cross-referenced against regional water quality and public wastewater treatment plant sources. Six facilities were found to have closed or moved outside the region, management of eight facilities deliberately chose not to respond to the survey, and data are missing from another eight facilities which did not respond to any attempts at contact. The survey thus has an uncertainty associated with non-response and lack of data from slightly more than a quarter of the identified facilities still presumed to be operating in the survey region. Additional effort is warranted to evaluate the resource potential associated with these other sources.

Although the total energy resource identified within the survey region is relatively small, potential exists for greater development of on-site power generation and other energy convertsion, including co-digestion in more centralized facilities or in manure digesters as the dairy industry expands waste treatment capacity. Where thermal load and natural gas offset are available, economics for facilities with long operating seasons and high capacity factor may be favorable in comparison with retail electric utility rates. Levelized revenue requirements for electricity from combined heat and power (CHP) facilities offsetting natural gas at $0.024/kWh and operating at annual capacity factors around 85% may be in the $0.02 - 0.03/kWh range, although technologies capable of meeting more stringent air regulations may be needed and incur higher costs. Similar revenue requirements for facilities operating only three months of the year increase to around $0.18/kWh. New feed-in tariffs for renewable energy and high summertime peak retail electricity prices suggest that additional investigations of facility designs for on-peak power generation would also be warranted.

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