An Assessment of the Recovery and Potential of Residuals and By-Products from the Food Processing and Institutional Food Sectors in Georgia

Executive Summary

The ultimate objective of this study was to identify and develop future opportunities and initiatives for the reduction and recovery of wastes generated by the food processing and foodservice sectors in the state. The food processing sector, as defined in the Standard Industrial Classification (SIC) system, represents a major portion of Georgia's industrial base, and in 1995 employed 58,700 workers, with total payrolls of $1.42 billion, and consumed $9.41 billion of raw materials to produce $16.21 billion of manufactured goods, with $6.80 billion of value added (U.S. Bureau of the Census, 1998). With respect to institutional food waste generators, restaurants employed 253,800 statewide, 139,700 of them in the Atlanta Metropolitan Service Area (Georgia Department of Labor, 2000). Other establishments considered potential generators of institutional food waste include retail food stores, educational institutions, healthcare establishments, correctional institutions, and hotels and lodgings. The potential for waste generation in the food processing and institutional food sectors, given their considerable size and broad scope, was thought to be substantial, hence the development of alternatives and opportunities for the reduction and recovery of these wastes was expected to have major impacts, not only in preserving solid waste disposal (i.e., landfill) capacity, but potentially in the economical operation of these industries as well.

Information on the quantities and characteristics of wastes generated by the food processing industries in the state of Georgia is severely limited, but these were initially estimated using throughput-based and manpower-based waste generation factors. Subsequently, a limited industry survey was conducted to better quantify waste generation rates and to identify waste utilization and recovery patterns. Institutional food waste estimates, on the other hand, were based solely on waste generation factors selected from the literature.

These studies revealed that the quantities of food processing and institutional food wastes generated in Georgia are considerable. Estimated generation rates and typical disposal and utilization methods for these residuals are presented in Table ES.1.

The Meat Products Industry which accounts for the largest employee base within the food processing sector, also generates the largest single by-product stream, 821,200 tons/year of inedible animal parts and meat. Most if not all of these materials, however, is converted by the rendering industry into animal feed. Large portions of this waste stream are generated in the Atlanta Regional Commission (127,600 tons/year), Georgia Mountains (192,900 tons/year) and Northeast Georgia (134,900 tons/year) Regional Development Council (RDC) coverage areas. Brewers' and distillers' grain and yeast (297,500 tons/year) and oilseed meals (810,000 tons/year) likewise represent substantial by-product streams.

Table ES.1 Estimated generation rates for food processing and institutional food wastes in the state of Georgia.

Waste Stream and Major Constituents	Estimated Quantity, tons/year			Utilization/Disposal Method
FOOD PROCESSING WASTE			**2,870,900**	
Animal Matter		**1,073,900**		
Offal, meat, bones, blood	821,200			Animal feed
Fish/seafood waste	6,800			Animal feed
DAF sludge	249,600			Animal feed
Eggshells	30,700			Land application, animal feed
Grain		**393,300**		
Waste flour or other ingredients, dough, or product, including dry cereal or snack chips	95,300			Animal feed
Brewer's/distiller's grain/yeast	297,500			Animal feed
Unusable feed	200			Landfill
Fruit and Vegetable		**235,200**		
Trimmings, fruit pomace	231,100			Landfill, land application, animal feed in limited quantities
Waste sauces, salad dressing	4,100			Composting/land application, animal feed possible
Nut and Oilseed		**1,168,800**		
Nut/seed hulls	358,800			Animal feed/bedding, composting, land application, filler material, fuel
Oilseed meals	810,000			Animal feed
INSTITUTIONAL FOOD WASTE			**474,200**	Landfill, limited composting
Commercial Establishments	422,000			
Educational Institutions	2,500			
Military Installations	8,500			
Health Care Establishments	6,400			
Correctional Facilities	34,800			
TOTAL			**3,345,100**	

Like inedible meat, these by-products are typically used as animal feed. Bakery wastes are also widely used for animal feed, and undergo a rendering or cooking process prior to feed formulation. On the other hand, fruit and vegetable trimmings (231,100 tons/year) and nut and oilseed hulls (358,800 tons/year) appear to be underutilized and may represent a resource recovery opportunity.

Estimated wastewater generation rates and typical characteristics for the food processing industry in Georgia are presented in Table ES.2. The total quantity of wastewater was estimated at 18.8 billion gallons annually, with a biochemical oxygen demand (BOD) load exceeding 200,000 tons/year. The organic load of the wastewater not only represents

Table ES.2 Typical Characteristics, Estimated Volume, and Estimated Organic Loading of Wastewater Generated by the Food Processing Industry in Georgia.

Industry Group	Estimated Wastewater Volume (million gallons/year)	Typical Characteristics	Estimated Organic Loading (tons/year BOD)
Meat and Poultry Products	10,730	1,800 mg/L BOD 1,600 mg/L TSS 1,600 mg/L FOG 60 mg/L TKN	80,600
Dairy Products	500	2,300 g/L BOD 1,500 mg/L TSS 700 mg./L FOG	14,900
Canned, Frozen and Preserved Fruits and Vegetables	2,080	500 mg/L BOD 1,100 mg/L TSS	4,300
Grain and Grain Mill Products	130	700 mg/L BOD 1,000 mg/L TSS	300
Bakery Products	530	2,000 mg/L BOD 4,000 mg/L TSS	4,400
Sugar and Confectionery Products	140	500 mg/L BOD	300
Fats and Oils	350	4,100 g/L BOD 500 mg./L FOG	7,000
Beverages	3,660	8,500 mg/L BOD	91,000
Miscellaneous Food Preparations and Kindred Products	700	6,000 mg/L BOD 3,000 mg/L TSS	5,600
TOTAL	18,810		208,600

Abbreviations: BOD, biochemical oxygen demand; TSS, total suspended solids; FOG, fats, lost product, but it is also converted into municipal biosolids. This becomes a problematic residual in publicly owned treatment works that receive the wastewater. Consequently, the wastewater represents a significant waste reduction opportunity.

Opportunities for the reduction and recovery of food processing residuals and institutional food waste are plentiful. The task is not to simply identify potential opportunities, but to focus on those that are technologically mature, or at least approaching that stage, and that can potentially effect substantial reductions in waste disposal volume and costs and accrue in economic benefits for the citizens of the state. Rather than focusing on specific potential products, technologies and sectors critical to the development food waste recovery processes are identified, and potential strategies to support the development and commercialization of these processes are discussed.

As indicated by Table ES.1, food processing residuals generated by the meat, poultry, seafood, bakery, and grain processing industries are substantially absorbed by the existing industrial infrastructure and converted into animal feed products, but collectively represent the largest waste volume in the food processing industry. Residuals generated by fruit and vegetable processing and by nut and oilseed processing, on the other hand, are substantially unused or underutilized. Waste from commercial and other foodservice operations, with the exception of a major composting enterprise operated by the Georgia Department of Corrections, is for the most part disposed of through municipal waste disposal systems. Potential strategies and initiatives for the reduction and recovery of these different residual materials will be considered. A number of initiatives are grouped together as a broad or overarching strategy, intended to impact a specific area or direction that affects food waste reduction and recovery. The remaining initiatives are grouped by type of activity, i.e., education/ technology transfer, research, and policy.

Water conservation should be aggressively pursued given that a substantial quantity of wastewater, estimated at 18.8 billion gallons/year, is generated. This wastewater is estimated to carry 208,600 tons of organic material (as BOD), hence the treatment of this wastewater in publicly owned treatment works (POTWs) results in the generation of another problematic residual, municipal biosolids. Furthermore, municipal water supplies generally undergo a series of treatment operations, including coagulation, sedimentation, filtration, and disinfection, operations which consume chemicals, energy, and manpower, and generate solid residuals. Therefore, if significant reductions in industrial water usage can successfully be realized, the potential impact is significant. In order to promote and achieve water conservation in the food processing industry, the following strategies should be pursued:

- Educational and outreach programs intended to train production and maintenance personnel and superintendents should be widely offered to industrial clients. These programs should be designed to provide as much practical, hands-on information as possible. These programs should be scheduled and located such that they would be accessible to plant personnel, and given typically tight productions schedules this will often mean that the programs will need to be held at the plant site, and that the training materials and equipment be sufficiently portable to permit this. These programs should also be delivered in a medium that permits free communication between the trainer and the target audience, and given the demographics of industry production workers this may require fluency in a language other than English.

- Training on techniques to limit the quantity of organic material carried by the wastewater, such as dry cleaning, spill control, microscreening, and membrane filtration, should be offered and conducted as well.

- Research aimed at developing sanitation and food safety practices consistent with HACCP objectives but entailing minimal water usage should be undertaken. This may include the development of alternative disinfection methods and the use of advanced techniques for detecting microbial contamination.

- Research and demonstration projects on industrial water reuse should be undertaken. The demonstration phase is critical for this activity to show that food safety goals can be achieved even with water reuse provided that the appropriate technology is used and is implemented in the proper manner.

- Research on the development of processing alternatives that minimize water usage should be undertaken. Examples include the use of steam rather than aqueous solutions for peeling operations and of air jets rather than water baths for initial cleaning in fruit and vegetable processing.

- A critical review of effluent regulations instituted by different local jurisdictions should be undertaken. Because water use reduction may result in increased effluent concentration, plants that undertake water conservation programs could potentially be penalized for their success if effluent regulations are based on concentration limits. Mass-based limits, on the other hand, would permit an operation to reduce the quantity of its wastewater while continuing to discharge the same amount of organic material. Hence, mass-based effluent limits appear more conducive to industrial water conservation, however concentration-based limits may be necessary to ensure reliable treatment plant performance. The development of effluent regulations that would address both of these objectives would require a comprehensive review of the wastewater load, the treatment capacity, and the effluent requirements of the POTW. Such an exercise should be encouraged by the state regulatory agencies, with technical assistance to be provided by the state body or by the GEP technical partners, if needed. Such a review might also be conducted in conjunction with a review of the billing structure for industrial water users, which can also be tailored to promote water conservation.

While the continuing depletion of non-renewable resources provides substantial impetus towards a biobased products manufacturing infrastructure, much of the infrastructure and technology required to achieve such a shift are not currently in place. Even in the case of ethanol production, which is a relatively mature industrial fermentation process, technologies for the production of ethanol from lignocellulosic waste via hydrolysis and fermentation have aroused little commercial interest. A novel technology for simultaneous saccharification and fermentation of 5- and 6-carbon sugars is in the early stages of a demonstration process, and could take several years to validate (National Research Council Committee on Biobased Industrial Products, 2000). Particularly with respect to by-product utilization, a collection infrastructure exists only for those residuals with established products and markets, and even then small-scale generators are rarely served by it. Consequently, the large-scale utilization of Georgia's food processing residuals and institutional food waste in industrial-scale by-product recovery operations would require both technological and infrastructure development.

A possible approach is described by the biorefinery concept (National Research Council Committee on Biobased Industrial Products, 2000). Like a petroleum refinery, a biorefinery would be a processing facility which utilizes one or a limited number of feedstocks to manufacture a range of products. A potential biorefinery facility could be based on a wet corn milling plant, which could potentially produce corn starch, corn syrup, dextrose, dextrins, organic acids and biochemicals, ethanol, and feed ingredients. Some lessons from the operation of petroleum refineries, which would also be applicable to biorefineries, include:

- Refineries produce more and more products from the same feedstock over time, thereby diversifying outputs.
- Refineries are flexible and can shift outputs in response to change.
- Processes in refineries improve incrementally over time.
- Process improvement invariably makes the cost of raw material the dominant factor in overall system economics.

With respect to waste reduction and recovery, a biorefinery operation would have a substantial incentive to develop alternative products and processes for by-product and waste utilization. Furthermore, a biorefinery would be well organized to pursue such possibilities, especially with respect to ensuring that by-product and residuals are of a quality suitable for recovery as other value-added products. Consequently, the development of biorefineries to undertake food processing activities would lead to the reduction of food processing residuals. For example, biorefineries could be established around two of the state's major crops, soybeans and peanuts. The possibility of soybean-based biorefineries producing oil, protein isolates, food products and supplements, and feed has been suggested (National Research Council Committee on Biobased Industrial Products, 2000), and the possibility of ultimately converting the hulls into chemical products would make such a venture more attractive. A similar biorefinery could conceivably be structured around peanut processing as well, although the current product range for soybeans appears broader, more diverse, and more versatile compared to peanuts. At the same time, nuts and oilseed hulls, estimated at 358,800 tons/year, are a major food processing residual, and are utilized primarily for composting, for animal bedding, and to provide roughage in feeds, although a limited quantity of pecan hulls is ground for use as filler in plastic production. Whether it would be more beneficial to a biorefinery to process the shelled nuts or seed, or shell the raw material on-site and use the shells to manufacture additional products would depend to a great extent on the products that could be derived from the shells. Regardless of whether or not shelling is integrated into the refinery operation, however, the lignocellulose represents a potential resource, and initial research efforts would focus on the conversion of the lignocellulosic material into fermentation feedstocks and chemical commodities, with more specialized chemical products targeted for longer-term development. The establishment of biorefineries based on soybean and peanut processing would also be consistent with the rural development goals enunciated by the state.

The biorefinery concept appears to hold up well for products such as corn,soybeans, and peanuts, which are rather versatile and from which a wide range of products can be manufactured through established technologies. Whether such an approach would be viable for another the state's major agricultural products, poultry, is another matter. In theory a wide array of products could be manufactured in an industrial complex having a poultry slaughter and dressing operation as its front end, including food additives, protein isolates, oil, biofuels, feed ingredients, and insulation. Additional development of many of these technologies is required, however, before such a facility can be realized. Furthermore, the establishment of biorefineries around poultry processing plants would challenge current industry practice of shipping residuals off-site for rendering into animal feed. The refinery could nevertheless be a useful model, due to the economic benefits of having multiple, tightly integrated, symbiotic operations at a single site.

In order to promote the establishment of biorefineries as a vehicle for rural development and more efficient resource utilization, the following initiatives should be undertaken:

- A committee should be appointed by the state to evaluate the feasibility of and develop an implementing plan for the establishment of biorefineries based on major agricultural products of the state. This could initially be limited to those products for which a wide range of processing options are currently available, i.e. peanut and soybean, and to those produced in an extremely large volume, i.e. poultry. The committee would identify potential research and technology requirements, financial requirements, candidate sites, and potential industry partners, among other things. Note that a committee constituted to evaluate the biorefinery concept would not be restricted to food crops, and would probably evaluate non-food crops (e.g., cotton) as well.

- Research that would expand the range of potential products from the candidate biorefinery crops should be undertaken. Examples of such research include the hydrolysis of nut hulls into fermentable carbohydrates, and enhanced oil recovery from poultry processing and subsequent biofuel production.

Regardless of whether the biorefinery concept is pursued, a strategy that would initially focus on established products, technologies, and infrastructure, while investing in the development and expansion of these for an eventual shift into more novel, higher-valued products, appears to be the most reasonable approach for enhancing waste recovery in the food processing and institutional food sectors. This does not necessarily mean that markets currently served by the residuals will be abandoned, but that alternative higher-value markets

Table ES.3 Current and potential products from different food processing residuals.

Industry/Activity	Residual(s)	Current Products/ Disposal Methods	Future Products	
			Intermediate	Long-term
Meat, poultry and seafood processing	Offal, blood, feathers, DAF sludge	Animal feed	Animal feed, including lactic acid fermentation	Protein isolates Animal fats, biofuels Insulation material
Bakery operations and grain processing	Waste doughs, breads, bakery ingredients, waste grain, spent brewer's/ distillers' grain/ yeast	Animal feed	Feed ingredients, via SCP production or lactic acid fermentation Fermentation feedstocks Commodity chemicals	Specialty chemicals
Fruit and vegetable processing	Trimmings, culls, fruit pomace	Landfill, land application, animal feed	Feed ingredients, via SCP production or lactic acid fermentation Methane/biogas	Biofuel(s) Commodity and specialty chemicals
Nut and oilseed processing	Hulls, meals	Compost, animal feed, plastic filler	Fermentation feedstocks Biofuel(s) Commodity chemicals	Specialty chemicals
Dairy products	Whey	Food and feed in limited quantities	Commodity and specialty chemicals	Specialty chemicals
Beverage products	Waste beverage	Municipal sewer	Biofuels	Specialty chemicals

will be sought and developed to enhance by-product recovery and to reduce potential constraints imposed by waste and by-product management requirements on future industry growth.

Current products from different food-based residuals are listed in Table ES.3, along with intermediate- and long-term product goals for these residuals. Among the food processing industries, the first four industry groups listed (meat, poultry and seafood processing; bakery operations and grain processing; fruit and vegetable processing; and nut and oilseed processing) produce the largest quantities of residuals and would probably deserve the greatest amount of attention and resources with respect to waste reduction efforts.

For meat, seafood, and poultry processing, the current residual collection and processing infrastructure appears effective in capturing substantially all of the waste material and converting it into animal feed. In addition, research on the conversion of these residuals into alternative, higher-value products has not been pursued as aggressively as research on the conversion of lignocellulosic wastes, except possibly in the area of enzymatic conversion, i.e., lactic acid fermentation into animal feed ingredients. Consequently, the lead time required for the development of new products from these materials is probably longer compared to other residuals, and the maintenance of the current residual recovery products and infrastructure would constitute the main intermediate-term objective.

Like meat, poultry, and seafood processing residuals, residuals from the bakery and grain processing industries are typically recovered as animal feed, with waste doughs even undergoing a rendering process to produce a dry feed ingredient. In contrast to those proteinaceous wastes, however, bakery and grain processing residuals contain a large amount of or are readily converted enzymatically into reducing sugars that can serve as feedstock for industrial fermentation processes. Since this material is primarily starch rather than cellulose or lignin, the hydrolysis process is much better established. Also, this material is solid or semisolid and could serve as a good substrate for solid-state fermentation processes. Potential intermediate-term technologies are the production of chemicals and SCP- or lactic acid-enhanced feeds through solid substrate fermentation, and of fermentation feedstocks and/or chemicals through hydrolysis and/or fermentation.

Fruit and vegetable processing residuals would be mainly cellulosic in nature, and although hydrolysis of this type of material is possible it has not been commercially applied to a great extent. Although potentially usable as animal feed, their high moisture content and low nutrient content makes the delivered cost of these residuals prohibitive. It may be possible to enhance the feed value of these materials through SCP production or lactic acid fermentation, but this may be difficult, particularly with vegetable trimmings, due to the limited concentration of fermentable material, unless supplemental substrate is provided, preferably in the form of a waste material with a complementary nutrient profile. An alternate course is to use anaerobic digestion to produce biogas, while the possibility of more desirable products through cellulose hydrolysis and fermentation is explored.

Whey produced by the dairy industry is used in both food and feed production, but in limited quantities only. As noted earlier, the supply of whey far exceeds the demand for products derived from it, and there are no new technological developments that promise to change this situation (Council for Agricultural Science and Technology, 1995). Nevertheless, the range of potential products from whey is large; and provided the necessary markets can be developed, the recovery of this residual should become a viable activity.

Residuals from the production of grain-based fermented beverages are generally utilized for food (brewer's yeast) and feed production, while the grape pomace generated by Georgia's small winemaking industry is returned to the vineyards to fertilize the next crop. Chemicals are potentially recoverable from the grape pomace via biological or chemical means, but the quantity of this residual is small. Waste beverage from soft drinks packaging operations, given its sugar content, is potentially usable as fermentation medium, perhaps requiring no more than pH adjustment prior to inoculation, and is a potential raw material for biofuels and chemicals.

Institutional food wastes are currently disposed of mostly through municipal solid waste management systems, i.e., by landfilling. One exception is the Georgia Department of Corrections food waste composting program, which diverts more than 8,500 tons/year of waste from landfills. However, this is only a small fraction of the total amount of institutional food waste generated in Georgia, estimated at 474,000 tons per year. Of that amount, an estimated 422,000 tons (89%) is generated by commercial establishments, of which restaurants produce the bulk. Consequently, institutional food wastes represent a large pool of material, and their reduction or recovery could potentially have a substantial impact on the quantity of food-based residuals disposed of in landfills. Other than composting, two possible means to recover the value in institutional food wastes are animal feed production and anaerobic digestion. Feed products obtained through the processing of institutional food wastes would be specifically prohibited from inclusion in swine rations, to avoid public and animal health problems, and standards on pathogen destruction, nutrient content and stability would have to be established and maintained. Nevertheless, and despite existing Georgia law, animal feed seems to be a product towards which institutional food wastes could readily be diverted. Anaerobic digestion is another alternative, although biogas is not considered a very desirable product. Over the longer term, the evaluation and development of the food waste as a feedstock in solid or liquid fermentation could be examined. The nutritional profile of the material may permit microbial cultivation with minimal micronutrient augmentation, enhancing the economics of its utilization. On the other hand, sterilization requirements for the waste may be more stringent compared to alternative raw materials. Another issue may be the potential variability in the composition of the waste. Particularly if the fermentation process places stringent requirements on medium composition, it may be necessary to limit the types of waste accepted, to frequently test the medium, to have alternative substrates for blending, or even to avoid use of the waste altogether. Solid substrate fermentations, however, are more flexible in this respect than traditional liquid phase fermentation processes, and could consequently be preferrable.

Application of a system for institutional food wastes recovery could be substantially constrained by the logistics of waste collection, considering that the bulk of the waste is generated by a large number of relatively small establishments that currently do not consider the disposal of their waste a problematic issue. However, when the feeding of these residuals to swine was permitted, these issues were apparently dealt with successfully by the swine farmers who collected and used the waste, so it is clear that these issues can be overcome at some scale. It may be possible to avoid these logistics issues during the technology development and demonstration phase by a undertaking a cooperative project with a large institutional food waste generator, possibly one with an established collection and/or recovery system. Wider-scale implementation of an institutional food waste recovery process, however, would require that these issues eventually be addressed and surmounted. With these concerns in view, the following initiatives are recommended to promote increased recovery of institutional food wastes:

- Review current regulations on the use of institutional food wastes for animal feeding, with the end result being the development of a policy structure that maximizes the beneficial reuse of institutional food waste for animal feeding purposes while safeguarding animal and human health.

- Assess the logistical issues related to the collection of institutional food wastes, particularly in situations where the waste is produced mostly by multiple small generators (e.g. restaurants) and develop management strategies and state-supported incentives that would permit potential processors to undertake this activity more economically.

- Research on the processing of institutional food waste into animal feed ingredients should be undertaken. The research would establish the processing methods and techniques required to eliminate or minimize the public and animal health risks associated with feeding institutional food waste to livestock.

- Research on the incorporation of processed institutional food waste into swine, dairy, beef cattle, broiler, and layer operations should be conducted. The research would also establish the levels at which the processed institutional food waste could be incorporated into feed rations while meeting the nutritional requirements of the animals and obtaining.

- Research on the use of institutional food for fermentation process feedstock should be conducted. The research would assess the preprocessing operations, e.g. grinding, homogenization, sterilization, nutrient supplementation, etc., required before the waste can be used for fermentation. The research will also investigate specific products for which the institutional food waste may be a particularly suitable raw material.

The need for more information on waste reduction and recovery programs and opportunities was identified earlier, hence education and technology transfer is an important component towards achieving pollution prevention goals. Specific initiatives in this area include:

- Technical assistance activities of the GEP partners should be continued and strengthened. Although it appears that relatively few companies are aware of them, these services are generally received quite positively. However, efforts should be made to more broadly promote GEP services to industry. The services provided by the GEP partners include:

    - Technical assistance through site assessments for waste reduction and recovery. Personnel from GEP partner organizations assist plant personnel in identifying and exploring waste reduction opportunities, and assist in the implementation of any waste reduction measures adopted.

    - Technical assistance in environmental and regulatory compliance. As noted earlier, the need to comply with environmental regulations is the common driving force behind waste reduction and treatment efforts. Personnel from GEP partner organizations have many times been called in initially to assist on environmental compliance issues, and any help provided in this area has in our experience always been greatly valued and appreciated and very well-received by industry. Such contacts provide the opportunity to have the client examine waste reduction measures as a means of achieving environmental compliance as well as cost reduction, and as an alternative to more conventional waste treatment or disposal methods. Technical assistance in the area of environmental compliance has proven a particularly effective means of introducing clients to potential waste reduction opportunities in their processing operations. Linkages between the GEP partnership, the Georgia Department of Natural Resources Environmental Protection Division, and local regulatory bodies should be cultivated to identify potential client companies that could benefit from waste reduction and recovery. This should not conflict with the non-regulatory role of the Pollution Prevention Assistance Division, since its services are restricted to technical assistance and technology transfer and it has no role in assessing environmental compliance. This assistance may involve helping clients to respond to a notice of violation from local or state environmental regulators, to identify waste reduction and recovery alternatives that may help achieve environmental compliance, and to decipher and comply with regulatory requirements and permit guidelines pertinent to their operation.

- Training on the use of full-cost accounting as a decision support tool in the institution of waste reduction measures should be provided to industry and corporate personnel. Very often, the true cost of a waste material is not realized. For process losses, e.g. spills, typically the only cost considered is the price of the material itself. For processing residuals, on the other hand, the costs of treatment and/or disposal are the main cost components considered. To reflect the true cost of the waste, the inputs involved in acquiring, handling, and processing the material prior to its becoming a waste, and the cost collecting, handling, treatment, and disposal of the waste should all be considered. Full-cost accounting techniques would consider all cost factors, and enable managers and manufacturing personnel to justify the cost equipment and operational modifications adopted to achieve waste reduction.

- Publish and circulate waste reduction guides targeted to institutional food waste generators. Such documents should contain simple, easily implemented measures for waste reduction explained in readily understandable language.

Research is required to validate the benefits and effectiveness of waste reduction and to develop technologies for resource recovery. Specific research needs include:

- Field-based grading and cleaning of the produce could substantially reduce the quantity of residual material generated at the processing plant, and facilitate the return of these materials to the soil. This practice should be strongly encouraged since options for the recovery of fruit and vegetable waste appear limited. Demonstration activities that would validate the benefits of this practice should be conducted, along with research to developed improved mechanical harvesting equipment.

- Research to improve and optimize the enzymatic hydrolysis of cellulosic and lignocellulosic substrates should be undertaken. Hydrolysis is a necessary step preliminary to fermentation for the production of ethanol, however improvements in conversion and yield of cellulosic and lignocellulosic substrates would probably need to be realized before commercial-scale application becomes attractive (National Research Council Committee on Biobased Industrial Products, 2000). Adoption and optimization of the hydrolysis process for different residual materials would therefore be a top research priority, and will be key to broadening the utilization of lignocellulosic material for industrial fermentation.

- Research on the development of alternative products from meat, poultry, and seafood processing residuals should be undertaken. These products could include lactic acid-enhanced feeds, protein isolates, animal fats, biofuels, and insulation material.

- Research on the bioconversion of wastes from bakery and grain processing should be performed. Enzymatic hydrolysis and liquid fermentation could be used to produce chemicals and fermentation feedstocks, while solid state fermentation could produce chemicals and SCP- or lactic acid-enhanced feeds.

- Research on the bioconversion of fruit and vegetable trimmings should be undertaken. The feed value of these materials could be enhanced through solid state fermentation, or energy could be derived from them through anaerobic digestion.

- Research on the bioconversion of nut and oilseed hulls should be undertaken. Hydrolysis of these lignocellulosic materials would produce fermentation feedstocks, which could subsequently be converted into chemical commodities.

- Research to quantify the benefits of composting and land application should be undertaken. The results of this research should be made available on a timely basis to the food processing industry, to institutional food waste generators, and to potential compost producers.

- Research on odor control and minimization in the rendering industry should be undertaken to secure this market for food processing by-products.

- Research to examine alternatives and/or enhancements to the dissolved air flotation process commonly used for separation of protein and fat from poultry processing wastewater should be undertaken. Alternatives techniques and end products for processing the DAF sludge should also be investigated.

- Research and demonstration on techniques that can be used for volume and mass reduction of food wastes prior to further processing and recovery should be conducted. Transport costs are expected to become a major factor affecting the profitability of resource recovery operations utilizing food wastes and techniques that would reduce waste volume and mass while retaining the desirable properties of the waste material could substantially reduce these expenses.

Policies that would promote waste reduction and utilization should be formulated and implemented. Potential policy initiatives include:

- Policies regulating the composting of food processing and institutional food wastes should be reviewed. For example, Permit-by-Rule provisions in the state solid waste regulations (Georgia Department of Natural Resources, 1997) apply only to operations where 75% or more of the composted material is generated on-site, although it is not clear why composters that obtain more than 25% of their material off-site pose a higher risk. While the need to safeguard public health and environmental quality is recognized, the solid waste regulations do not in general encourage composting, and should be modified to promote resource recovery.