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Energy from Waste and the Food Processing Industry

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Abstract

The provision of a secure, continuous energy supply is becoming an issue for all sectors of society and the food processing industry as a major energy user must address these issues. This paper identifies anaerobic digestion as an opportunity to go some way to achieving energy security in a sustainable manner. However, a number of energy management and waste reduction concepts must also be brought into play if the environmental, social and economic aspects of sustainability are to be balanced. The reporting of such activity will help to promote the green credentials of the industry. Cleaner production, supply chain and life cycle assessment approaches all have a part to play as tools supporting a new vision for integrated energy and waste management. Our reliance on high-energy processing, such as canning and freezing/chill storage, might also need re-assessment together with processing based on hurdle technology. Finally, the concepts of energy and power management for a distributed energy generation system must be brought into the food processing industry.

1. Introduction

The food processing industry (FPI) is the major manufacturing sector in the UK (about 15% of the total manufacturing output with a turnover of £70 billion) and a major employer (about 400-500,000 people directly, about 14% of the total manufacturing workforce). It is the fourth highest industrial energy user (70 TWh and 13 million tonnes of carbon dioxide in 2000) (Carbon Trust, 2006) and also a waste producer in its own right and any steps it takes towards sustainable practices will be a major benefit in the UK fight towards a sustainable future. The waste arisings in the UK food industry supply chain indicate that the manufacturing element (FPI) generates about 2.5 million tonnes of food waste (about 50% of total food manufacturing waste) compared with 8.3 million tonnes of food waste generated by households and 600,000 tonnes by the hospitality industry.(WRAP, 2010, 2011). The sector includes over 6,500 businesses most of which are small or medium-sized enterprises.

However, as a processing sector the FPI sits in between the supplier of its raw materials (agriculture and fisheries) and its consumers (the food retail sector and ultimately the consumer – you and me). The FPI is the buyer of about two-thirds to three-quarters of all UK agricultural produce and involves about 1.2 million people indirectly in the food supply chain. Thus, when considering the sustainability credentials of the FPI we must take into account its position in the supply chain from raw materials to final disposal. A decision on the limits of the responsibility of the FPI will have a marked influence on the sector's impact on the environment (such as energy usage and Greenhouse Gas (GHG) emissions), society and economics. It could be argued that the major arbiters of sustainability are the big supermarkets which dominate UK food retailing and who, in appealing to consumer pressure for sustainable foods, make demands on the FPI and before that to the agriculture and fishing sectors for sustainable practices which can be evidenced. Techniques such as Life Cycle Assessment (LCA), Carbon Footprinting (CF), Eco-labelling, Supply Chain management and responsible resourcing have all been used to promote the sustainability credentials of the food industry as a whole. The Triple Bottom Line (TBL) approach which recognises the need for environmental, social and economic balance in attaining sustainability should be reflected by companies in their Corporate Social Responsibility (CSR) activities.

Food processing covers a wide range of technologies which are designed to make the final products safe, stable and attractive to the consumer (a combination of different flavours, aromas and textures). These technologies involve varying degrees of energy consumption in the primary production, processing (see Table 1), retail distribution, use by the consumer and final disposal. Another major concern for the sustainability of the FPI is water usage which occurs in cleaning and washing; grading and transport and process heat, steam generation and cooling operations. Water usage is also associated with the generation of polluting effluents and the potential loss of valuable by-products. These four elements: energy, water usage, effluents and valuable by-product recovery are crucial elements in improving the sustainability of the FPI and are also bound up in the concept of cleaner production which is a process analysis aimed at roughly the same goals. All these issues are considered for the fish processing industry as a good example for the challenges facing the FPI generally (Hall, 2010). This paper will deal only with energy, indicating sustainable generation options and the wider concepts associated with this particular process element which must be addressed to provide an all-encompassing solution.

2. Energy

The high energy usage in the FPI (as indicated in Table 2 in comparison to other industrial sectors) allied to the rising cost and tighter availability of fossil fuels suggests that alternative, long-term energy supplies must be investigated. The extent of autogeneration of electricity by the food industry is currently low, averaging around 400 MW annually from 2005 – 2010. (DECC, 2011), suggesting that there is a big gap between consumption and autogeneration which could be made up, to some extent, by appropriate renewable energy recovery from wastes.

In addition, new attitudes to energy management and accounting are required and even a reassessment of how we process and distribute food in an energy-limited world. The first consideration is deciding the most appropriate alternative energy system for the FPI taking into account the resources at its disposal, energy demands and site-specific issues. In addition, the management and integration of energy generation and usage for the FPI must take its place in the wider context of national energy strategy and policy. Finally, we must identify the tools which will allow a thorough analysis of energy usage so that improvements can be evidenced.

2.1 Anaerobic digestion

Given the nature of the raw materials available one technology which seems well suited to the FPI is Anaerobic Digestion (AD) a process in which biodegradable material is broken down by micro-organisms, in the absence of oxygen, to yield biogas (mainly methane with some carbon dioxide).

The process typically operates at mesophilic (25 - 45^{o}C) or thermophilic (55 - 70^{o}C) temperatures with the higher temperature range enhancing the extent and rate of biogas production but at the expense of the need for greater control and sophisticated equipment. A low temperature (psychrophilic) system (5 - 15^{o}C) is possible providing a simple, low cost but low performance option. The AD process can be batch or continuous, the raw material at high or low solids content and operated in single or multistage fashion. Some plants operate a pasteurisation process to ensure bacterial hygiene in the final digestate to conform to the EU Animal By-products Regulations where appropriate (EU Commission, 2002) although the thermophilic process should meet these requirements. The raw material can be, "seeded" to establish a high population of anaerobic organisms and speed up the AD process. Thus, we have a flexible system which could be operated in association with a food processing plant under a variety of conditions and technology levels. Other products from the AD process are a nutritious liquor (which if not utilised is a potential pollutant) and a solid residue (containing lignocelluloses, for example, unaffected by the AD organisms) which can be used as a soil conditioner. The process is the same as that which occurs naturally in landfill but the methane is utilised rather than contributing to GHG in the atmosphere. The methane produced can be used to generate heat and/or electricity (mainly via Combined Heat and Power (CHP) plant), fed into the national grid (as biomethane) or used as a vehicle fuel, after suitable removal of contaminants in both cases, some may be recycled to provide thermophilic conditions in the AD plant. Thus the AD process contributes to a reduction in GHG emissions (and carbon footprint) by:

- the replacement of fossil fuels (resource substitution)
- reducing methane from landfill (carbon dioxide produced by burning the methane is about 25 times less damaging as a GHG and is recycled by green plants)

- reduced vehicle movements (the waste is used on-site) which complies with the proximity principle of treating and processing waste as near to the source of production as possible
- biogas and/or electricity are used on-site (no losses in electricity grid transmission, typically 9%) (Environmental KTN, 2007).

In addition, the use of AD by food processing plants is attractive because:

- it contributes to energy security for all or part of their processing needs and by the sale of excess energy to a national supply grid
- most food wastes can be utilised alone or in combination
- the AD plant will be on-site so there is no need to move potentially dangerous wastes off site with the need for movement permits
- many food processing factories will be purpose-built on sites distant from the general public so that common environmental nuisances (smell and vermin) can be minimised (these are important planning issues in the UK)
- food processors are experienced in handling their processing wastes and understand their nature
- the AD process (a fermentation) is not unfamiliar technology for food processors
- the AD technology is well established (SCP, 2008).

Another concept driving AD as an energy option is that of, "decentralised energy", also known as distributed energy. The concept covers a wide range of technologies not reliant on the high-voltage electricity transmission network or a gas grid and leads to:

- the efficient use of energy by CHP and reduced transmission losses (30-40% of power station fuel is converted to waste heat and cooling requires access to adequate water supplies)
- the use of renewable low CF energy sources
- flexibility of generation
- energy security
- an awareness of energy generation by the community through closer engagement with the generation process – a very necessary attitudinal change.

Barriers to the take-up of AD (or any other decentralised energy generation) by industry are a combination of financial, technology and management issues. Financial considerations include the current high initial capital cost of new technology which should be offset by lower operating costs (cheaper energy) and the means to achieve a balance between these two elements. Other financial considerations are the arrangements for buying and selling energy to a national grid, and fluctuations in fuel prices which make the calculation of savings difficult. These are essentially accounting issues and may require a new management vision if the new technologies are to be given a fair chance. Application of a full LCA and CF for a process which account for the full cost of carbon (and emissions) might be such a vision. Although decentralised energy technologies are well developed and proven there is still uncertainty attached to them in some quarters which could be ameliorated by the introduction of validation and certification schemes and development of a service and maintenance sector in support of the technology. Finally, there is a need for a new generation of decentralised energy sector professionals to manage the technology, regulatory issues such as planning and the contractual relationships covering the energy produced (Environmental KTN, 2007).

In addition, the take-up of any new technology is also affected by political, macro-economic and social factors which can act as stimulants or barriers e.g. Renewable Energy Certificates (ROCs) are awarded in the EU to renewable energy sold to the central electricity network which works as a financial incentive. Feed-in-tariffs (FIT) have been introduced in the UK since April 2010 along similar lines to encourage renewable energy generation, reward reduced use of the grid and to pay for power exported to the grid. On the other hand low landfill taxes will encourage that practice by being cheaper than installing technology to utilise the waste. The EU approach is for a steadily increasing land fill tax which will one day make the alternatives attractive (SCP, 2008).

Another influence on FPI energy performance is the UK Government CRC Energy Efficiency Scheme (previously the Carbon Reduction Commitment) which is a mandatory scheme to report and price carbon emissions from substantial energy users (more than 6,000 MWh pa equivalent to an annual energy bill of £500,000). The CRC came into force in 2010, aiming to drive down carbon emissions, and in the light of experience since that date a simplification of the scheme is being put in place. Participants in the scheme will be able to buy allowances for carbon emissions annually (based on their previous year’s emissions) and those showing good carbon emission reduction will benefit year on year. The scheme will publish performance league tables giving participants a reputational incentive through reporting their carbon reduction activities. Thus, the socio-political dimensions of energy management, carbon reduction and climate change will have a bearing on the approach of the FPI to technologies such as AD.

The AD process itself consists of four biological stages in transforming the raw material into the biogas (see Figure 1):

- ***hydrolysis*** of the large organic polymers (carbohydrates, lipids and proteins) into their small molecular weight constituents (simple sugars, fatty acids and amino acids)
- ***acidogenesis*** conversion of the small molecular weight components into carbonic acids, volatile fatty acids (VFA) and alcohols with hydrogen, carbon dioxide and ammonia as by-products. High levels of VFA will reduce the system pH which will inhibit the methanogenic bacteria in stage four below.
- ***acetogenesis*** conversion of products of acidogenesis into mainly acetic acid (with carbon dioxide and water) through the action of acetogenic bacteria
- ***methanogenesis*** conversion of acetic acid (and hydrogen produced along the way) into methane (with some carbon dioxide and water) which occurs best at pH 6-5 – 8.0 through the action of methanogenic bacteria. The composition of the biogas can range from 50 - 75% methane and 25 – 50% carbon dioxide with traces of other gases such as hydrogen sulphide, nitrogen and hydrogen. These minor contaminants must be removed as they cause corrosion in generators, vehicle engines and mains pipelines. The conversion of biogas to biomethane, suitable for mains injection, also increases the calorific value of the product.

The extent and rate of conversion of raw material into biogas is highly dependent on the nature of the feedstock which, above all, should be of consistent composition and free of contamination by plastic, glass and metal. The raw material C:N ratio is important as ammonia is a potent inhibitor of the methanogenic bacteria so that protein-rich raw material (such as from fish processing) may require balancing with the addition of carbohydrate-rich material (Ward & Slater, 2002). On the other hand carbohydrate-rich material leads to high VFA and hence low pH, also inhibiting the methanogenic bacteria, which can be buffered by the ammonia producing protein-rich material. However, co-digestion of carbohydrate-rich and protein-rich materials does not always give the expected results (Callaghan *et al.*, 2002). Moisture content is crucial in terms of mechanical handling, pumping and plant size but also determines the hydraulic retention time (HRT) for the process – the time during which the material is held in the reactor. Liquid wastes tend to have a short HRT but solid wastes may take over 30 days and require good mixing (Ward & Slater, 2002). These are all factors which for a food processing plant are under their control as they are using their own materials and are responsible for their condition.

Other technologies for converting waste to energy over a range of conditions exist such as:

- direct combustion (incineration) using high capacity (100 - 250,000 ton per annum) conventional fluidised beds and, “moving grate”, systems. Great care must be taken to ensure complete combustion and flue gas clean up takes up a considerable part of the process. Incineration in approved plants is the only route for the most dangerous, Category 1, food by-products (EU Commission, 2002) and probably not appropriate for energy substitution in the FPI
- gasification where the biomass is heated (above 750^{o}C) in a low-oxygen atmosphere to generate syngas, a mixture of hydrogen and carbon monoxide, which fuels a generator for electricity (and heat in CHP). Plasma systems (at 6 - 10,000^{o}C) yield gas and a vitrified slag.
- pyrolysis in anaerobic conditions (above 430^{o}C) yielding a crude petroleum-like mixture including fuel gases. Pyrolysis at 250 - 300^{o}C yields biochar which is added to soils to improve fertility and sequester carbon (Sohi *et al*., 2010) as in the terra preta soils of the Amazon basin .

When compared to these alternatives AD is a good option in terms of conversion efficiency, scale of operation, carbon savings and affordability (Defra, 2007). For AD the conversion efficiencies are 30 – 35% (for electricity) and 80% (for CHP) and a 20,000 ton per annum plant needed a capital outlay of £7.3 million (Defra, 2007). A SWOT analysis for anaerobic digestion for food processing waste indicates the issues facing the up-take of this technology. The Strengths relate mainly to the suitability of the technology to food wastes generally and the Weaknesses are for specific food wastes as a raw material (and the need for co-digestion mentioned earlier) with some process scale and materials handling problems. The Opportunities are great and are mainly in the need for the food processing industry to respond to the changing energy provision situation whilst the Threats are from competing technologies and peripheral activities. For example, small scale wind turbines (rated at < 50 kW) and designed for the specific food processing plant site would be an alternative and compatible technology provided the wind conditions were suitable. Such a threat, if it exists, could be overcome by an energy management system which utilised both forms of energy generation (see *2.3* below). However, the latest UK Government AD Strategy and Action Plan emphasises the importance of waste-to-energy conversion and the great potential for the technology to utilise FPI wastes (Defra, 2011).

The inevitable result of the continuing focus on energy and waste savings in all aspects of society (brought about by the climate change and the global energy resource and supply debates) is the integration of energy and waste management in the processing industries. The use of carbon as a currency of account would connect these, apparently different, aspects of production. The feasibility of using waste as a source of energy, as opposed to conversion to other valuable by-products, will become an issue as cost and availability of fossil fuels becomes problematic. For example, energy usage in the transport of food and food products is an important factor, particularly where international trade is common. The production of biodiesel as a transport fuel from seed oils by transesterification of the triglycerides into methyl esters is well established and the use of fish oils as a raw material has also been demonstrated. The biodiesel could also be used in generators for off-grid electricity production. This is still an example of by-product utilisation, but shows, once again, that there is scope for the FPI sector to work beyond its normal boundaries in a sustainability area to beneficial effect.

2.2 Energy saving and alternative processing

The manipulation of temperature for food processing and in the supply chain has overtaken other traditional methods such that heat processing, mechanical drying and the removal of heat are the predominant methods of food preservation in the developed world. Processes based on salting, pickling, fermentation and other means of altering water activity are seen as poorer products. Notwithstanding the interest in Europe and North America in, “ethnic”, foods with strong flavours, many consumers have lost the taste for high salt, vinegary or fermented flavours, odours and tastes. Their presence has also been associated with, “chemical”, food, unnecessary additives and, “E numbers”, all with negative connotations. However, these low-tech approaches are also low energy, being effective at ambient temperatures and form the basis for many traditional foods where empirical approaches have developed products over many years (Leistner, 2000).

The use of a combination of barriers to microbial growth and possible spoilage or pathogenicity has been called, “hurdle technology”, (Leistner, 1978, 1985) and many potential hurdles for foods have been identified (Leistner, 1999) including those which also change the food flavour in addition to enhancing safety (for example the products of Maillard reactions). Table 3 gives a list of selected hurdles which could be applied and the use of high or low temperatures are included although, with sustainable processing in mind, hurdle technology should be applied to reduce the severity of heat treatments and the need for low temperature storage. The hurdle technology approach has not been widely adopted through a combination of consumer and producer perceptions of the danger of, “getting it wrong”, and the relatively low cost of energy which make thermal processing acceptable. The need for a more sustainable and energy efficient FPI should bring about a reassessment of multi-barrier food processing.

In the meantime, efforts are being made to make inevitable heat-related processing, such as thermal processing and freezing/chill storage more energy efficient. Energy savings can be made retrospectively or, better still, done at the initial design stage and should be allied to good management practices which make the best use of the specific process characteristics. For example energy consumption can be reduced in the freezing/chilling sector by:

- reducing the freezing time as this will reduce other energy usage associated with the central process
- reducing heat leakage caused by poor insulation of the pipes and valves and through the doors and curtains in cold stores. Good cold store management will reduce the number of loading and unloading events and lessen the frequency and length of time when doors are open and also the contribution from the body heat of workers in the store and so save on the energy required to maintain the cold store temperature
- limiting defrosting cycles. Defrosting is necessary to remove moisture (from the food product) which has been circulated to the condenser, reducing its efficiency, and must be removed by closing down the freezing operation and warming the condenser to melt the ice. The need for defrosting can be reduced by packaging and good plant management – balancing freezing rate against defrosting schedules

- controlling the use of heat-generating fans which circulate air in the system as significant energy savings can be made without compromising the freezing rate

- Lighting controls can be motion activated to dim the lights when not needed and energy-savings bulbs and lighting strips can all contribute to less energy usage and maintain the cold store temperature

- recycling waste heat removed in the freezing operation, where condenser heat in particular can be used for pre-heating boiler and clean-up water.

Attempts to improve the freezing process usually concentrate on reducing the freezing time and techniques tend to be adjuncts to the conventional technologies and have not yet achieved commercial acceptability. Some examples are:

- *partial freezing* where the fish is reduced to a temperature below -1°C with only 30-70% of the water frozen (“superchilling”) has been described for many years (Kreuzer, 1969).

- *ultrasonics* involves the use of sound waves throughout the product to increase ice crystal nucleation leading to small crystals and better texture (Nesvadba, 2003).

- *Pressure shift freezing* is another process giving rapid ice crystal nucleation throughout the product. The product is first pressurised to 2000 atmospheres, chilled to -18°C and, on release of the pressure, rapid nucleation of the liquid water takes place, followed by further freezing (Li and Sun, 2002). There are some problems with the combination of technologies at play but research continues, particularly in Japan (Kolbe and Kramer, 2007) where high pressure food processing is well developed.

- *adsorption refrigeration* has been promoted as an energy efficient process which can utilise waste energy from other parts of the processing plant, from renewable sources (geothermal or solar) and from diesel generators which are common in off-grid locations. It is also based on ammonia as the refrigerant and water as an adsorbent (good sustainability options). The process uses molecular forces and thermal energy for compression of the refrigerant and release to the high-pressure side of the cycle unlike a conventional mechanical system (Kallenberg, 2003). .
- *air-impingement freezers* are air-blast systems with high velocity jets directing cold air onto the food surface which favour rapid freezing rates for thin products (fish fillets for example) similar to cryogenic systems (Salvadori and Mascheroni, 2002).

2.3 Energy management

Energy management has already been mentioned in the context of the attitude of the FPI to new energy generation, such as by AD, and the need for a new vision was proposed through new approaches to financial and energy accounting (LCA and CF). However, the emergence of distributed/decentralised energy generation (for example, AD, wind, solar, tidal, micro-hydro and ground-source-heat-pumps) in tandem with current centralised power generation (conventional power stations and the national grid) also demands a new vision for Energy and Power Management (EPM). An EPM system is required which can monitor and control multi-directional energy flows to ensure security of supply (for example, local, “Islands”, of generation which could be linked to a, “Mainland” grid), best-cost supply (in-house or grid) and develop the contractual/commercial relationships which would be governed by these EPM systems. The evolution of a, “Smart Grid”, is the current holy grail and will rely on a new generation of monitoring devices and, most importantly, communications for the control and coupling together of more than one energy generation regime at a specific location and its relationship with a national grid (Rodriguez-Roncero, 2008). A food processing plant could utilise a combination of wind, solar and AD energy to be used for heat and power (via CHP) and for fuelling its vehicles and reduce dependency on the national grid. Future developments should allow energy storage and possibly hydrogen-based fuel options. The concept of EPM must be embraced by all energy users from large utilities to individual homes; the FPI is no exception and given its high energy usage should be one of the flag bearers for this new approach.

3. Supply chain approach

Successful companies, particularly those large companies with many business interactions, have used interventions in the supply chain to streamline operations and gain commercial benefits through: increased efficiency and productivity; product development and reduced waste. A reasonable question to ask is, can the same approach reduce GHG emissions, reduce the CF and promote reduced energy consumption? The answer is undoubtedly, “Yes”, but when GHG emissions, an LCA or a CF are taken into account current operations along the supply chain might require change to have a positive environmental impact. Actions to reduce the CF, such as energy (or water usage) reductions, will also give overt economic benefits (or might not be considered for implementation at all) but can also contribute to good public relations (contributing to CSR and the TBL). The supply chain approach must be applied in an all-embracing manner, rather than each company in the chain (including the central operation) looking only at the contribution of their own activities with a cumulative effect– which would be the traditional way to proceed. Such a co-ordinated approach demands collaboration (and trust) up and down the supply chain, around the central operation, with savings being identified for the product as a whole. The Carbon Trust in the UK is one organisation which has developed supply chain models and supported case studies (Carbon Trust, 2006). Figure 2 illustrates the components of the supply chain carbon savings methodology indicating where carbon savings can be made by the central operation and the supply chain. There is great emphasis in the analysis on energy saving and generation to reduce the CF.

The FPI which processes primary products for the consumer is a good example of the supply chain approach. The emissions associated with supplying food to the plate can be divided into: direct emissions from energy consumed in the home; indirect emissions from the supply chain and travel emissions in getting the food to the home. Direct emissions in the home represent about 23%, indirect emissions along the supply chain are 69% and transport is 8% (Carbon Trust, 2006). Thus, the food industry has a large supply chain component which, if mobilised appropriately, could have a massive SD impact and the central company by influencing its suppliers could have global impact and deliver genuine TBL benefits. The FPI with its emphasis on trade, and particularly developing-to-developed country product flows could be a prime example of beneficial supply chain interventions. For example, Iles (2007) argued that seafood producers could be made more accountable through a production chain view and associated pressures making them more transparent in the process and suggested ways to achieve this, such as:

- identify and track companies to remove their invisibility
- develop product chain campaigns so that companies influenced each other

- develop mechanisms to compare companies to improve industry practices
- develop methods to track consumption, production and management changes
- develop interactive consumer tools so that consumers get feedback on their purchasing habits which can also be fed back to the producers.

Further, Thrane *et al* (2009) emphasised the importance of the supply chain approach for ecolabelling which would include not only the fishing operations but also the post-landing operations which have been shown to have high environmental impact.

4. Global Reporting Initiative reporting

The Global Reporting Initiative (GRI) has developed sustainability reporting guidelines to encompass the three areas of the TBL – the current guidelines are the third generation (G3) and still subject to scrutiny and change. Starting from a number of common principles the reporting framework (based on the G3 guidelines) includes specific sector supplements to reflect unique sectoral issues and community impacts. It is also developing supply chain sustainability issues through a Global Action Network (GAN) project (Global Reporting Initiative, 2010). Food Processing is one of the specific sectors covered and the main sector topics for reporting were developed in a two year process involving a varied working group from the FPI and are given here:

- Sourcing
- Labour/management relations
- Healthy and affordable food
- Public policy

- Costumer Health and safety
- Product and service labelling
- Marketing communications
- Breeding and genetics
- Animal husbandry
- Transportation, Handling and Slaughter.

The topics listed above reflect the particularly sensitive business of food production and the consumer's perception of the industry where expectations are becoming more and more stringent. Energy generation and savings are not included but a similar exercise done now would undoubtedly have it high on the agenda. A fundamental question raised earlier is whether there can be a coherent approach to sustainability in the FPI sector and, if not, is this important? The development of a standardised set of sustainability criteria would have benefits such as:

- making realistic comparisons between companies and different sub-sectors
- ensuring robust methodologies of assessment through application in a variety of settings
- making knowledge transfer from industry-to-industry or academia-to-industry easier
- establishing a common language of sustainability to be used in negotiations and enforcement of (inter)nationally agreed treaties and protocols
- giving legitimacy to CSR and make communication with the lay public more transparent
- reducing the cost of producing LCA through economies of scale and standardisation of inputs with IT-based support.
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At the same time the different scale of operation and range of processes and products within the FPI sector militates against a rigid approach and some sub-sectors face specific sustainability issues which must be addressed in a unique manner – energy usage being a good example. GRI does provide downloads of protocols addressing the topics listed above as reporting guidelines (Global Reporting Initiative, 2010). Although only one approach to sustainability reporting in business the GRI does point the way towards making the TBI the real bottom line.

5. Cleaner Production

Cleaner Production (CP) aims to reduce waste, generate new products and reduce energy and water usage as a contribution to the LCA of the FPI and has been defined as, "the continuous application of an integrated, preventive, environmental strategy applied to processes, products and services to increase overall efficiency and reduce risk to humans and the environment", (UNEP, 2000). A similar approach is that of, "eco-efficiency", which recognises the need for sustainable exploitation of renewable natural resources, such as for food production.

The application of CP in the FPI is significant because of its central role and major contribution to the CP and LCA of food products. CP can be applied: from product and process design, through distribution to final disposal in a pro-active manner rather than as an, "end-of-pipe" application (i.e. it can also be applied through the supply chain). The application of a CP assessment follows a very similar series of phases as does the LCA such that information gleaned for one form of assessment could be used for the other. The CP assessment phases are: Planning and organisation; Pre-assessment; Assessment; Evaluation and feasibility study and Implementation and continuation (UNEP, 1996) and thus very similar to those of the LCA. The contribution of CP (and eco-efficiency) to the SD agenda could evolve in such a way that the three concepts may become inseparable in time and CP will contribute to the TBL through protecting the environment, process worker and consumer, improving process efficiency and increasing profitability and competitiveness (UNEP, 2000). The social benefits accruing from this approach could be direct, in job security and profits shared by all, and indirect through long-term sustainability of the FPI.

6. LCA development

Life Cycle Assessment (also called Life Cycle Analysis) is the investigation and evaluation of all the environmental impacts of a given product, process or service. Concepts such as CF and Ecolabelling rely on LCA for their credence as it is provides a methodology which has some international standing and uniformity. However, there are variants on the basic LCA definition, some being broader or narrower than others and an LCA can be used for specific elements of a product stream, such as energy, although there is scope for error due to the complex supply chains involved in the FPI, as mentioned above. The brief description of an LCA process given here is based on that of the International Standards Organisation 14040 Series which is a generally recognised (ISO, 2006). The origins of the approach can be traced back to the 1970s in the UK, USA, Sweden and Switzerland (Boustead, 1996, Hunt and Franklin, 1996, Oberbacher *et al*., 1996) and its development in the FPI at large has been supported by work in Scandinavia (Morgensen *et al.,* 2009).

An LCA will normally be divided into four activities:

Phase 1: ***Goal and Scope*****:** the goal decides which aspects of the operation are included (setting the system boundaries), whether all aspects are included or specific aspects such as energy. The system boundaries are set by the scope definition and can be divided into four phases: (1) pre-manufacture, (2) manufacture, (3) packaging and distribution and (4) use and end of life. Consideration of all phases would be, "cradle-to-grave", or can be more limited such as, "cradle-to- factory gate", which would only include the first two phases. This phase also decides the purpose of the LCA and for whom it is being done as this will affect the data collected and its conversion to meaningful units.

If a processing plant produces more than one product (co-products) then there must be an allocation of impact between them. The simplest approach is that of system allocation which can be made on the simple basis of the mass of product or the economic value of the product. However, this approach does not seem to discern between any differences in process operations which lead to the co-products – not all process operations have equal impact. An alternative approach (preferred by the ISO 14040 series) is system expansion whereby the co-products are considered as alternatives to other products available globally and an allowance made for this substitution in calculating the impact for the main process.

Phase 2: Inventory analysis**:** is a data collection phase and includes all inputs (e.g. energy), outputs (products) and emissions (to air, water, soil and solids) or those selected for inclusion. Accurate, relevant information is essential and must be available or derived from secondary data such as utility bills for gas and electricity. Various databases exist for generic activities such as conventional electricity generation and some for specific food processes to make life easier. This activity is the most time consuming and challenging if a company has not attempted any such exercise before. It is also revealing for a particular site to discover whether its overall utility bills are accurate and adequately reflect the distribution of energy usage on-site. For energy savings to be made it is essential to pinpoint the, "hot spots", and this might entail sub-metering within the overall plant set-up. Furthermore, a production system can be broken down into unit processes, batch or seasonal/annual production, whichever best defines the system in meaningful numbers – this is called the functional unit.

Phase 3: Life Cycle Impact Analysis**:** in this activity the inventory analysis information is processed and first of all assigned to an environmental impact category with appropriate units which may conform to systems such as ISO 14000 Series or be process-specific. Six common environmental impact categories are:

- ***global warming*** where the main contributor is combustion of fossil fuels for various reasons and expressed as carbon dioxide equivalents (most relevant to energy generation and resource substitution by renewable generation)
- ***acidification*** which affects waters, forests and in some cases buildings is caused mainly by combustion for electricity, heating and transport and expressed as sulphur dioxide equivalents
- e***utrophication*** which leads to algal blooms and oxygen depletion and fish deaths is caused mainly by fertiliser nitrogen run off into waters and expressed as nitrate equivalents
- ***ozone depletion*** caused by man-made halocarbons (CFCs, HCFCs etc)
- ***land use*** in the production of products and expressed as hectares per year (or m^2 per year)
- ***photochemical*** smog from volatile organic compounds (VOCs) produced from unburnt petrol and diesel and organic solvents causes respiratory problems and reduces agriculture yields - expressed as ethane equivalents.

These categories are not exclusive and for certain applications the categories can be simplified or made process-specific. Once categorised, any emissions should be converted to the reference units for that category using equivalence factors. For CF, and hence energy-related calculations, all inventory items are equated to GHG emissions and will require conversion to carbon dioxide equivalents for other gases, such as methane. Udo de Haes and Heijungs (2007) discussing the use of LCA in energy analysis recognised its fundamental importance in all life cycles and capability of being separated from other aspects. The traditional form of energy balance familiar to all process engineers is analogous to an LCA in many ways suggesting that tools for energy analysis within an LCA for the FPI will become available.

A sensitivity check will determine the accuracy of the inventory data whilst a normalisation process will compare the relevant data to a reference system such as an existing process, for example. Normalisation gives a relative magnitude of the process under consideration against impacts which are known and already quantified. Finally, the inventory data can be weighted in terms of the most important environmental impact. The weighting criteria are, again, areas of debate and can be based on: the judgement of a panel of experts; financial considerations and targets set by the company or government edict.

Phase 4: Life Cycle Interpretation**:** the results of the impact analysis are compared with the original goal and scope of the project and judged, somewhat subjectively, against them. This analysis need not be left until the end of the LCA process but can take place continuously to ensure that the LCA is really achieving the goals and the scope is correct. This iterative approach to the interpretation of data will allow incremental improvements and/or changes to the goals and scope as necessary. The final interpretations should indicate the completeness of the data, the appropriateness of the analysis and reach conclusions and lead to recommendations for process improvement.

These four core elements of LCA are available in several software packages which lead the user through the phases, provide generic categories and conversion factors and impact assessment models. Variants for specific applications and sectors abound and international cooperation has lead to greater uniformity and consolidation of methodologies (Finkbeiner *et al.*, 2006). A recent review of LCA in the food industry (Roy *et al.*, 2009) described its use for a variety of agricultural products (bread making, dairy, meat among others) but also included packaging, land and water use and waste management considerations. Common problems were: a lack of common functional units, the influence of non-food usage of crops such as for biofuels and the purpose of an LCA itself in a world with population, land and water pressures. To reflect the latter case the functional unit could be the provision of a secure, healthy or a balanced diet and the production, distribution and consumption of foods should reflect this in any LCA. Indeed the LCA approach has evolved, such that now separate environmental LCAs (E-LCA) and social LCAs (S-LCA) are recognised (Benoit *et al.*, 2010). A combination of an S-LCA with the GRI approach would lead the FPI towards the full TBL as the socio-economic spheres are addressed.

As mentioned earlier, there is a demand for a new vision of energy management in the FPI and the thorough application of an LCA and a supply chain methodology are the potential tools which would give a sustainability-orientated approach. Figure 3 shows the basic system boundaries which could be set up to isolate a food processing plant from peripheral activities (factory gate-to-finished product approach) for energy generation and usage, but indicating the nature of the external activities. Although limited it does offer the factory the opportunity to assess the central operation of the FPI concerned. When supported by a supply chain analysis the influence of the peripherals can be added in perhaps with overall energy saving potential. The ability to use these tools to give a specific and global view of an FPI will demand a new vision by management, a new accountancy and sustainability awareness not recognised in the past.

7. Conclusions

If the FPI is to get to grips with energy management it must embrace the widest definition of the subject and utilise the tools at its disposal to achieve these aims. The UK multi-agency Global Food Security Strategic Plan 2011-2016 has four research themes, of which, two are resource efficiency and sustainable food production and supply, with GHG, energy and waste reduction as major goals within these themes. The strategic plan is a response to the national and global drivers which will impact and on food security and hence on the FPI ***and its supply chain*** (author's emphasis). Therefore, the use of CF and LCA, the Supply Chain approach and the advent of smart grids and a new energy management vision will all be needed for the strategy to succeed.

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