# final report

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# Quantifying the Water and Energy Usage of Individual Activities within Australian Feedlots

## Part B Report: Energy Usage at Australian Feedlots

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# Abstract

Whilst total annual energy records by lot feeders are usually good, little data exists on actual usage levels in individual components viz water supply, feed management, waste management, cattle washing, administration and repairs and maintenance.

Eight feedlots were selected representing a cross-section of geographical, climatic and feeding regimes within the Australian feedlot industry. The sub-system boundary as defined here is the feedlot site itself plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot.

At seven of these feedlots, power meters were installed to allow an examination of usage by individual activities. The major energy (viz water supply, feed management, waste management, cattle washing) usage activities were monitored and recorded.

This report provides factual information on the quantity of energy used within individual activities of seven Australian feedlots for the period March 2007 to February 2008.

# Executive Summary

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) has undertaken a project (FLOT .328) to measure environmental costs associated with the production of one kilogram of meat from modern Australian feedlots. As part of this project factual information data on water use was obtained via a detailed on-line survey of feedlot inputs and outputs including cattle numbers, intake and sale weights, dressing percentages. Annual water usage was estimated on the basis of one kilogram of dressed hot standard carcass weight gain (kg HSCW gain). In this context, HSCW gain is the difference between total dressed carcass weights of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot.

Whilst, total annual clean water and energy records by lot feeders are usually good, little data exists on actual usage levels in individual components viz water supply, drinking water, feed processing, cattle washing. Hence, more information is required on the water usage of individual components before these figures can be reliably reported.

The purpose of this study is to quantify the clean water, indirect and direct energy usage from individual feedlot activities. Eight feedlots were selected such that the feedlots represent a cross section of geographical, climatic and feeding regime diversity within the Australian feedlot industry. The sub-system boundary as defined here is the feedlot site itself plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot.

Water meters and/or power meters were installed at eight feedlots to allow an examination of usage by individual activities. The major clean water-using activities include cattle drinking water, feed management, cattle washing, administration, repairs and maintenance and dilution of effluent. Similarly activities that use a significant amount of energy include water supply, feed management, waste management, administration and repairs and maintenance.

The water and power meter data collected will be supplemented with existing data collected on-site including fuel consumption (diesel, LPG) and cattle performance data. Performance data will include market types, incoming and outgoing liveweights, dressing percentages, feed data and other parameters that allow HSCW gain to be estimated. Information will be collected on a monthly basis and collated.

The data will be analysed to obtain water and energy use associated with a number of feedlot indices including a per head basis, per tonne grain processed and per kilogram of Hot Standard Weight gain (HSCW). A breakdown of resource use within the major feedlot activities and associated operations will be provided.

This report covers the issue of energy usage by feedlots.

Results from the seven feedlots studied showed that total annual indirect energy use ranged from 1.6-8 MJ/kg HSCW gain over the period March 2007 to February 2008. Distance travelled by trucks transporting cattle and delivering feed has a large impact on the energy consumed. Combined these represent a similar usage level to direct energy consumed within the feedlot subsystem.

Incoming cattle energy usage typically ranges from 0.1 MJ/kg HSCW gain to 2.0 MJ/kg HSCW gain, when cattle are sourced close to feedlots, however can range up to 4.5 MJ/kg HSCW gain. Outgoing cattle energy usage typically ranges from 0.5 MJ/kg HSCW gain to 0.9 MJ/kg HSCW gain, however a figure of 2.8 MJ/kg HSCW gain has been measured. The average annual commodity delivery energy usage ranged from 0.8 MJ/kg HSCW gain to 5.2 MJ/kg HSCW gain, however a figure of 5.4 MJ/kg HSCW gain has been recorded.

The indirect energy usage figures illustrate the proximity of respective feedlots to cattle, abattoirs and commodities. These figures also are influenced by the differences in average daily gain between long fed cattle and domestic cattle, number and type of commodities used in rations (high grain versus high roughage). These results also clearly show the impact of the drought (grain and available cattle supply) and high grain prices on the industry in particular during the later half of 2007 and early 2008, where higher energy usage figures were recorded.

Results from the seven feedlots studied showed that total annual direct energy use ranged from a low 0.9 MJ/kg HSCW gain to 8.3 MJ/kg HSCW gain over the period March 2007 to February 2008. Expressed on a per head basis total annual energy usage ranged from 444 MJ/head to 1483MJ/head. The total energy usage is primarily dependent on the type of feed processing system in use.

A wide variation was measured in water supply energy usage. On average, water supply represents in the order of 3% of the total energy usage. Expressed on a per head basis it ranged from 0.04 MJ/head to 6.6 MJ/head, with an average in the order of 2.5 MJ/head.

Water supply energy usage between feedlots is dependent on a number of factors, including depth to groundwater and distance to supply. Within feedlots water supply energy usage is directly proportional to the water pumped per month. Additional energy is used with having to deliver water to the pens via a pumping system compared with a gravity supply system. In this case, energy consumed in delivering water to the pens can be similar to that used in supplying water to storage facilities.

Feed management is the largest single consumer of energy in the feedlot as expected. For those feedlots with steam flaking systems it contributed on average approximately 80 % of total usage, whilst those feedlots which process their grain by other means it represents around 45% of total energy usage.

Feed management energy usage has been proportioned into feed processing and feed delivery usage. Feed processing energy usage on a tonne of grain processed basis ranged from 20 to 365 MJ/t grain processed. Three different feed processing systems are represented within the seven feedlots. For feed processing systems other than steam flaking, average energy usage is typically less than 50MJ/t grain processed. For steam flaking, the total energy usage ranges from 280 to 365MJ/t grain processed. Hence, there is a large variation between feed processing systems and between feedlots with the same system.

The average feed processing electricity energy usage measured ranges from 20 to 50 MJ/t grain processed. The variation in electricity energy usage may be attributed to monthly variation in grain delivery, movement and storage and milling efficiency (tonnes per mill).

For steam flaking systems, a review of individual feedlot monthly feed processing data shows that there is an increase in energy usage during the cooler winter months. Hence, more energy is required to heat water and increased heat transfer losses. Setup and operation of feed processing systems will also influence total energy usage.

Feed delivery energy was measured and comprised electricity used by stationary mixers, diesel consumed by loaders during feed loading and by feed trucks delivering ration to pens where appropriate. The average feed delivery energy usage measured ranges from 26 to 52 MJ/t ration delivered. A number of different feed delivery systems are represented within the seven feedlots. This includes stationary mixing, bunker system, batch boxes and a number of varying combinations in mobile equipment. Mobile equipment combinations included tractor/trailed mixer units, ROTO-mix trucks (various capacities and number), loaders (number, no of ingredients and bucket capacities) and screw mixer trucks. Whilst feed delivery energy usage is dependent on the system and equipment utilised, pen layout and feedout method also influences the energy used.

Expressed on a per head on feed basis, the average annual waste management energy usage ranges from 6 to 15 MJ/head on feed/month. As expected, pen cleaning contributed the highest proportion of the total waste management energy usage. On average, pen cleaning energy usage ranged from 5 to 8.5 MJ/head on feed/month, however usage figures up to 27 MJ/head on feed were measured in one month. Manure stockpiling represents on average around 15% of the total energy usage, however can range up to 45%. The variation between feedlots can be attributed to the various manure management systems employed at each feedlot. It is driven by the frequency of cleaning, equipment used and the volume of manure removed.

Cattle washing energy usage ranged between an average 0.02 MJ/kg HSCW gain (0.3 %) and 0.1 MJ/kg HSCW gain (1 %) of total energy usage. The energy consumed in cattle washing is directly related to the volume of water used. The average cattle washing energy usage on a per head washed basis ranged from 1 to 12 MJ/head washed. The predominant energy source is electric, however an electric and diesel powered pumping system are used.

Administration and minor activities (cattle management, repairs and maintenance) contributed an average 0.01 MJ/kg HSCW gain and 0.58 MJ/kg HSCW gain (1 %) of total energy usage. Typically, administration and minor activities represented between 4 and 20% of the total energy usage on a per kg HSCW gain basis. The higher usage is associated with the warmer months, hence air conditioning of the office facilities is driving energy usage in these cases.

Cattle management energy usage includes both processing and hospital activities, and represents electricity used for lighting, cleaning and restraint facilities. The average energy usage for cattle management ranges from 0.10 MJ/head processed to 5 MJ/head processed.

Repairs and maintenance includes electricity usage in workshop facilities as well as diesel usage from mobile plant used in repair and maintenance activities. The average energy usage for cattle management ranges from 0.4 MJ/head on feed/month to 4.5 MJ/head on feed/month.

Actual energy usage levels within individual activities have been recorded in seven feedlots representative of the Australian Feedlot Industry. These included water supply, feed management, waste management, cattle washing and administration and minor activities (cattle management and repairs and maintenance).

The outcomes of this study will allow the feedlot industry to develop a better understanding of the impact and relativity that various feedlot sector operations have on overall energy consumption. This information is invaluable for future design and management considerations. This study offers individual feedlot operators the opportunity to identify options for conserving energy in the feedlot and estimated cost benefits for alternative management practices if they were implemented.

Knowledge of the total energy consumption will allow the industry to benchmark itself against other intensive or extensive livestock industries and or industrial processes.

The outcomes of this study will allow the feedlot industry to start benchmarking total water usage, hence addressing the public misconceptions associated with the water used in the production of one kilogram of grained beef. In addition, this information is invaluable for participating feedlots in understanding the drivers of drinking water consumption and targeting high water use areas for efficiency gains and for future design and management considerations.

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# 1 Background

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) to address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will use the standardised tool, Life Cycle Assessment (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air. The goal of the LCA is to identify key environmental impacts of products. Environmental impact categories considered in LCA include but are not limited to resource energy, climate change (global warming), eutrophication, acidification, human toxicity (pesticide use) and land use.

LCA is a form of cradle-to-grave systems analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. LCA can be used to compare alternative products, processes or services; compare alternative life cycles for a product or service; and identify those parts of the life cycle where the greatest improvements can be made. An international standard has now been developed to specify the general framework, principles and requirements for conducting and reporting LCA studies (Standards Australia, 1998). LCA differs from other environmental tools (e.g. risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) in a number of significant ways. In LCA, the environmental impact of a product or the function a product is designed to perform is assessed, the data obtained are independent of any ideology and it is much more complex than other environmental tools. As a systems analysis, it surpasses the purely local effects of a decision and indicates the overall effects (Peters et al. 2005).

The functional unit for COMP.094 was the output of 1 kg of Hot Standard Carcass Weight (HSCW) meat at the abattoir gate. "Hot" indicates the meat in question has not entered any chilling operations. This output-related functional unit was chosen, rather than an input-related one, in order to describe the human utility of the processes under consideration – the provision of nutrition for people. Although the meat could be served in different ways, this functional unit makes the different processes under consideration "functionally equivalent" from a dietary perspective.

In LCA methodology, usually all inputs and outputs from the system are based on the 'cradle-to-grave' approach. This means that inputs into the system should be flows from the environment without any transformation from humans and outputs should be discarded to the environment without subsequent human transformation (Standards Australia, 1998). Each system considers upstream processes with regard to the extraction of raw materials and the manufacturing of products being used in the system and it considers downstream processes as well as all final emissions to the environment.

FIGURE 1 shows the generalised system boundary for the red-meat sector as defined for the COMP.094 project. Within this boundary, there is a sub-system for the feedlot sector. The boundary chosen here (shown in red on FIGURE 1) is the feedlot site itself plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot.

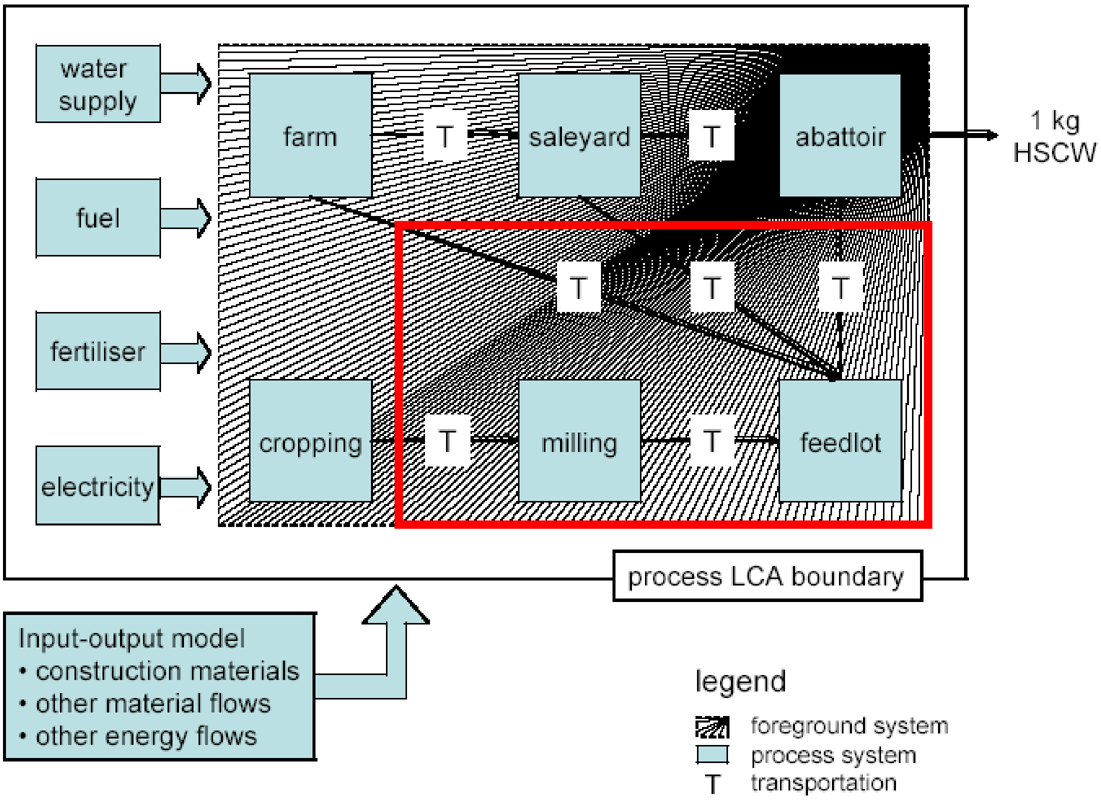



**Figure 1 - Generalised system model for the red meat sector with feedlot sub-system**

As part of the COMP.094 industry project, the beef cattle lot feeding sector has recently completed a related MLA project (FLOT.328) that will contribute to the whole-of-industry dataset, but more importantly addresses the public misconceptions concerning the environmental sustainability of the feedlot industry. The Terms of Reference for FLOT.328 required the researchers to address, in the context of a LCA, the feedlot-relevant natural resource management (NRM) issues water quality and water use efficiency, salinity, soil erosion, nutrient management and soil acidification, weeds, feral animals, biodiversity, vegetation management, energy efficiency and greenhouse gas emissions and solid waste. These issues were identified as issues of concern to the red meat industry.

The outcomes of FLOT.328 identified and quantified, where possible, the environmental costs (water, energy, GHG, and nutrient cycling) associated with the production of one kilogram of grained beef. It provided factual information on the volume of clean water and energy used at Australian cattle feedlots under a range of climatic, size and management conditions.

This study found that, whilst total annual clean water records by lot feeders are usually good, little data exists on actual usage levels in individual activities, viz. drinking water, feed processing and cattle washing. In addition, little is known about the variation in water use throughout the year. Similarly, total annual energy consumption records were usually limited by the lot feeders inability to separate out the electricity consumption of individual activities. Hence, more information is required on the water usage and energy usage of individual components before these figures can be reliably reported.

MLA's goal in commissioning this project is to address the lack of accurate data and quantify the contribution of individual feedlot activities on the total annual water usage and total indirect and direct energy usage. A breakdown on energy usage within a feedlot and comparison against other sites will allow energy efficiency programs to be instigated.

## 1.1 B.FLOT.0339 project description

The purpose of this study was to quantify the clean water usage and indirect and direct energy usage from individual feedlot activities. An MLA steering committee oversaw the selection of the feedlots such that the feedlots represented a cross section of geographical, climatic and feeding regimes within the Australian feedlot industry.

The sub-system boundary, as defined for the feedlot sector in FLOT.328, has been adopted for this project. The boundary (shown in red on FIGURE 1) is the feedlot site itself plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot.

Water meters and/or power meters were installed at eight feedlots to allow an examination of usage by individual activities. The major clean water-using activities include cattle drinking water, feed management, cattle washing, administration, repairs and maintenance and dilution of effluent. Similarly activities that use a significant amount of energy include water supply, feed management, waste management, administration and repairs and maintenance.

The water and power meter data collected was supplemented with existing data collected on-site including fuel consumption (diesel, LPG) and cattle performance data. Performance data included market types, incoming and outgoing liveweights, dressing percentages, feed data and other parameters that allow HSCW gain to be estimated. Information was collected on a monthly basis.

The data was analysed to obtain water and energy usage associated with a number of feedlot indices including a per head basis, per tonne grain processed and per kilogram of hot standard carcase weight gain (kg HSCW gain). A breakdown of resource use within the major feedlot activities and associated operations was provided.

# 2 Project objectives

The primary objectives of the project were as follows:

- To capture the clean water and energy usage from individual activities and performance data from eight feedlots representing a cross section of geographical, climatic and feeding regime diversity within the Australian feedlot industry, thus allowing the clean water and energy usage to be evaluated on the basis of one kilogram of dressed hot standard carcass weight gain (kg HSCW gain).
- To communicate the results of the study to MLA in a format suitable for dissemination to industry stakeholders.

The outcomes of this project will allow the feedlot industry to develop a better understanding of the total annual clean water and energy usage and the relativity and contributions that various feedlot sector activities have on annual clean water and energy usage. This will allow the industry to reliably report actual usage levels in individual components, viz. drinking water, feed management, cattle washing etc. Data will be used for individual feedlot planning, for industry wide planning, e.g. FLOT.132 – Vision 2020 project, and to propose water use and energy efficiency options for feedlots.

This report covers the issue of indirect and direct energy usage by feedlots. Indirect energy usage within the feedlot sub-system includes transport of cattle into and exiting the feedlot and commodity delivery. Direct energy usage includes consumption within the major feedlot activities of water supply, feed management, waste management, cattle washing and other minor uses including administration and repairs and maintenance.

This report presents a background literature review of indirect and direct energy usage at feedlots, data collection and results, as well as an analysis and discussion of the data collected.

## 2.1 Project reporting structure

This project includes the collection and analysis of a large quantity of data from operational feedlots on the water and energy usage associated feedlot operation. All data will be standardised to a number of indices including a per head basis, per tonne grain processed and per kilogram of hot standard carcase weight gain (kg HSCW gain). To ensure all this data and information is presented in a suitable manner, two reports will be compiled.

A. Water usage at Australian feedlots. This report presents a background literature review of water usage within individual activities of feedlots, data collection and results, as well as an analysis and discussion of the data collected. It includes consumption within the major activities of cattle drinking water, feed management and cattle washing and other minor uses such as administration and repairs and maintenance.

B. Energy usage at Australian feedlots. This report presents a review of total direct and indirect energy usage at feedlots, data collection and results, as well as an analysis and discussion of the data collected. It includes consumption within the major feedlot activities of feed management, water supply, waste management, cattle washing and other minor uses including administration and repairs and maintenance. In addition, indirect energy consumption within the areas of incoming and outgoing cattle and commodity delivery are included.

# 3 Literature review

## 3.1 Energy supply

Energy is fundamental to a feedlot production system with a reliable energy supply required to operate and maintain feed supply to the cattle. Furthermore, in recent years, there has been a substantial increase in the cost of energy. Despite this, there has been little research into energy usage at feedlots. Rather, the energy requirements of feedlots have been estimated from several studies undertaken in North America in the 1970's and 1980's. In a 2006 study, Davis and Watts (2006) investigated total energy usage of Australian feedlots. They found that, whilst total energy supply data was available, it was difficult to separate usage into activities.

Feedlots use energy directly as fuel or electricity to operate machinery and equipment, to heat or cool buildings, lighting and office equipment and indirectly through incoming and outgoing cattle and commodity delivery.

At the feedyard level, energy use is classified as either direct or indirect.

Direct energy usage is primarily petroleum-based fuels to operate vehicles, trucks, tractors and other mobile machinery for feed delivery, waste management and administration. Natural gas, LPG, butane and electricity are used to power grain processing equipment, water supply and cattle processing equipment. Electricity is used for lighting, heating, and cooling in offices and staff amenities. The predominant energy sources are 3-phase electric power and diesel fuel. Single-phase power and petrol fuels are also used. Facilities with steam flaking feed processing may also use gas (LPG, natural, butane and solid fuel such as coal) as a fuel source for the boiler/s.

Indirect energy usage is off the feedlot site and includes transport of cattle to and from the feedlot and in the delivery of ration commodities.

Sweeten et al. (1986) report on several US studies that determined the amount of energy utilised at cattle feedlots in Texas. In a 1979 Texas Cattle Feeders Association (TCFA) study, Sweeten and McDonald (1979) reported that for feedlots that processed grain by steam flaking, the total annual electricity usage was 60 kWh per head of feedlot capacity. In a 1985, TCFA study, electricity usage for feedlots who processed grain by steam flaking was 77.3 kWh/yr per head on feed.

Davis and Watts (2006) found that total annual electricity usage ranged from 32.6 kWh to 52 kWh per head on feed. This study incorporated feedlots that processed their grain by steam flaking, reconstitution and tempering.

Sweeten et al. (1986) found that total energy usage was 1298 MJ per head of feedlot capacity. Davis and Watts (2006) found that total annual energy usage ranged from 450 MJ to 1300 MJ per head of feedlot capacity depending on type of grain processing method used. They found steam flaking systems accounted for the highest total energy usage when compared with reconstitution and tempering methods.

## 3.2 Energy usage in individual feedlot activities

### 3.2.1 Feed management

Feed management involves feed preparation and quality control, nutrient balancing, feed bunk management, mixing and feed delivery. The feed preparation component incorporates grain unloading, movement, storage and processing and processing of roughage. The feed delivery component incorporates feed mixing and delivery to livestock.

*Feed preparation*

Cattle fed in feedlots require a scientifically-formulated grain-based ration to meet production and economic performance demands and target specifications. Metabolisable energy and crude protein are the major components that need to be met in a formulated ration, followed by minerals and vitamins. The various commodities used in the formulated ration will depend on the nutrient requirements needed to meet the desired level of cattle performance, the nutrient content of the feed, the availability of the feed, and current price of the commodity (Forster, 2006).

Grain-based finishing rations typically contain over 80% cereal grains on a dry matter basis (Watts & Tucker, 1994). Hence, infrastructure associated with grain processing is a predominant component of the feed preparation facility.

It is more economical for smaller feedlots to obtain processed grain off site, either as a single commodity or in the form of a pre-mix, due to the reduced quantity required. For larger feedlots, it is more essential to have a processing system on site due to the large quantities of grain required each day. Both steam flaking and reconstitution systems require the most costly infrastructure, followed by tempering.

The feed preparation facility consists of a composite of simple components and processes. The major components may include storage structures, handling equipment, grain processing and feed mixing operations. Whilst many of the components are interactive, component design, selection, maintenance and operation can influence the overall energy efficiency of the feed preparation facility. Electricity is the predominant energy source. It is utilised in the operation of electric motors in the mechanical grain handling and processing activities. Gas, diesel and solid (coal) fuel are used in boilers for heat/steam generation and mobile equipment respectively. PHOTOGRAPH 1 illustrates a typical grain storage system.

Feed processing methods are designed to improve the starch availability of grains, which in turn improves digestion and feed efficiency (Sweeten, 1990). Various processing methods are used to produce a physical or chemical change in the grain.

‘Wet’ processing systems are more energy dependent than ‘dry’ processing methods due to the additional processing required. However, a number of components such as grain movement and roller milling are still required irrespective of the processing method.

**Photograph 1 - Typical grain storage system**

Some of the processing methods used in Australian feedlots include:

- Dry-rolling. Dry rolling the grain involves passing the grain between two rotating corrugated rollers that crack or crush the kernels. This disrupts the integrity of the seed coat and reduces the particle size.
- Steam flaking. This involves steaming grain under atmospheric conditions for 15 to 30 minutes at 95 to 110°C, before rolling the grain to produce a thin, digestible flake. The flaking process gelatinises the starch (hydration or rupturing of complex starch molecules), resulting in moisture content of 18 to 22% (Davis & Watts, 2006). Hence, this process requires energy for grain movement, to generate steam for processing and rolling.
- Reconstitution. Reconstitution increases the moisture content of the grain from approximately 12% to 28-30% by storing the grain in an airtight vertical silo for 21 days (minimum of 14 days), before passing the grain through a roller to disrupt the integrity of the outer seed coat. The ensilage process improves the digestibility of the grain by altering the nature of the endosperm. However, results may become variable if the process is not carefully monitored and controlled (Holcomb & Klett, 1994). The energy consumed in this process is predominantly utilised for grain movement and rolling.

Individual feed processing equipment may include boilers for heat/steam generation and/or hammermills and roller mills for grinding or rolling. These processes are described in detail in other works (Holcomb & Klett, 1994; Sweeten, 1990). Photograph 2 illustrates a typical steam flaking boiler and steam chest.

Flaking mills are among the largest consumers of energy in the feed processing facility (Roth, 2007). Roth (2007) also states that they are also among the least efficiently operated in many circumstances.

In studies in North America, feed processing has been identified as the largest single consumer of energy. Sweeten and McDonald (1979) found that steam flaking required in the order of 1010 cubic feet (28.6 kL) of natural gas and 60 kWh of electricity per head of feedlot capacity. This equates to approximately 1065 MJ of natural gas energy and 221 MJ of electricity consumption per head per year. Sweeten et al. (1986) undertook a similar survey of Texas feedyards in 1985 and, for steam flaking, found similar natural gas energy consumption and slightly higher electricity consumption of 274 MJ per head per day.

Lipper et al. (1976) found that feed processing accounted for 56.7% of the total energy use in Kansas feedlots. However, the USDA estimated the energy use for feed processing and distribution accounted for 39.9% of the total energy (Sweeten, 1990). This work also found lower consumption of natural gas and electricity and hence probably does not reflect steam flaking, dry rolling or dry heating of grain. It would appear to be more reflective of self-mixing trucks using whole grain rations (Sweeten, 1990). Steam flaking is the most energy intensive grain processing alternative (Schake et al. 1981).

**Photograph 2 - Typical steam flaking system - Boiler (Left) and Steam Chest (Right)**

*Feed delivery systems*

Feed delivery systems are generally planned during the design phase of a new feedlot. The optimal layout and design of the feedlot is often site and size specific, which will ultimately affect which feed delivery system will be used and the energy efficiency of the system.

The distance needed in the delivery of rations to livestock, often twice a day, makes fuel, labour and equipment costs a high priority in the design phase (Drouillard, 2004). The components of the feed delivery system, once installed, are not frequently changed due to the high capital costs involved with infrastructure. However, changes may be considered during major renovation of an existing feedlot, such as increasing the feedlot capacity (Reed, 2001).

**Photograph 3 - Pen layout will affect the efficiency of the feed delivery system**

The feed delivery system will be determined by the type of feed-out system installed. Self-feeder bins are commonly used in small or opportunity feedlots, whereas open feed bunks are used in the large or commercial feedlots. In this study, all participating feedlots had the open feed bunk system.

Open feed bunks (PHOTOGRAPH 4) cater for all types of rations, partially rations processed on-site that are fed out once or twice a day. Open feed bunks are located along the fence line on the outside of the pen. The components of various types of feed delivery systems are discussed below.


**Photograph 4 - Open feed bunk commonly used in large feedlots**

*Feed mixability and delivery*

Ration consistency is the most crucial factor that directly or indirectly relates to the proper nutrition and high performance of cattle. Variation in feed can significantly affect the final nutrient composition ingested by the animal (Turney, 2005). By optimising the mixability of the feed, the cattle are given the best opportunity to obtain exactly what the nutritionist has formulated. The various ration ingredients need to be mixed thoroughly. Aspects that may affect mixability include mixing action, mixing time, sequence of ingredient addition, accuracy of addition and the type of feed delivery. The high range in particle size, ranging from coarse grains and roughage, to liquids and fine chemical particles, increases the challenge of a uniform ration (Turney, 2005).

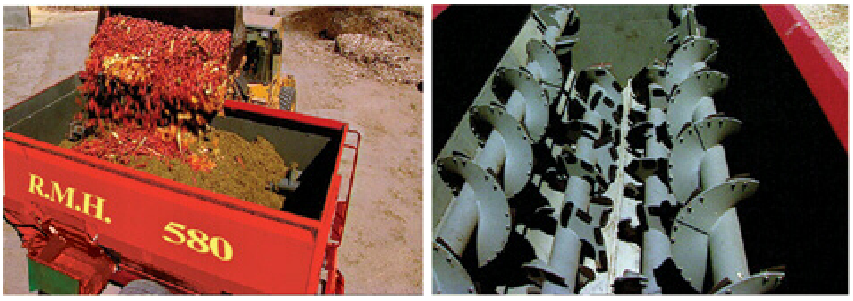
The type of mixer will vary according to the size of the feedlot, the ration, and method of feed delivery. Mixers can be categorised as either stationary or mobile with either horizontal or vertical mixing actions. As the name suggests, stationary mixers are permanently stationed with the ingredients weighed and mixed in the mixer feeder and the fed out using alternative equipment. The vertical feed mixer (Photograph 5) is often less efficient than the horizontal feed mixer (Photograph 6) due to its reduced size, restricting the level of liquid addition and requiring a longer mixing time (Reed, 2001). The disadvantage of all stationary feed mixers is the need for alternative equipment to deliver the feed. Hence, there are relatively few stationary mixers within the Australian feedlot industry.


**Photograph 5 - RMH stationary vertical mixer suited for smaller feedlots (RMH, 2003).**


**Photograph 6 - RMH stationary horizontal mixer suited for smaller feedlots (RMH, 2003).**

An alternative to the stationary feed mixer is the mobile feed mixer. Mobile feed mixers can either be trailed (behind a tractor) or permanently mounted on a truck. Mobile mixers allow the feed to be mixed on-the-go whilst the feed is being delivered, therefore, avoiding the need for double handling. PHOTOGRAPH 7 shows a typical trailed vertical feed mixer. PHOTOGRAPH 8 shows a horizontal feed mixer trailer. These are commonly used in small to medium sized feedlots.


**Photograph 7 - RMH vertical feed mixer trailer (RMH, 2003).**




**Photograph 8 - RMH horizontal feed mixer suited to small and medium feedlots (RMH, 2003).**

Medium to larger feedlots are more suited to using a truck mounted with a mixer feeder. This increases feed mixing and delivery efficiency due to the speed at which the feed can be delivered and, most importantly, the time it takes for the ration to be mixed. The mounted mixer feeder caters for all types of commodities within the ration from grains to liquids. Typically, the mixer feeder is mounted on load-cells to record the loading of each commodity. Depending on the size of the feedlot, more than one truck can be utilised. This allows a truck to be delivering the feed while the other truck is being loaded. There are two common types of truck mounted mixer feeders including the screw mixer and paddle type 'Roto-mix'.

The screw mixer has two top augers rotating in opposite directions and two non-continuous bottom augers for effective mixing of a large volume of ration (RMH, 2003). Photograph 9 shows an

International truck mounted with a 480 RMH David Evans Group screw mixer feeder. Typically, liquids are placed in the mixer following a grain commodity to prevent balling.

**Photograph 9 - Truck mounted with a RMH David Evans Group screw feed mixer.**

The paddle type ‘Roto-mix’ mixer feeder is quickly becoming the predominant configuration in use in larger feedlots due to claims of increased mixing efficiency, consistency of the ration and reduction in fines. There has been limited work undertaken to assess the energy efficiency of the screw and paddle type systems. The ‘Roto-mix’ mixer feeder consists of a horizontal rotor that lifts the feed upwards to the upper and lower side augers, which then move the feed from end-to-end for a thorough mix (Photograph 10). The tumbling action mixes the lighter roughage and high moisture ingredients without grinding or high pressure feed movement, resulting in a fluffier, more palatable ration (ROTO-MIX, 2006). The rotor and augers may be stopped or running while the truck is mobile. However, they must be going during feed delivery as it aids in the flow of the feed to the bunk.

**Photograph 10 - Diagrammatic representation of the Paddle Type ROTO-mix (ROTO-MIX, 2006).**

Photograph 11 displays a truck mounted 920 -18 'Roto-mix' mixer feeder.

**Photograph 11 - Truck mounted 920 -18 'Roto-mix' mixer feeder**

*Bunker System*

The most commonly used method of feed mixing and loading in Australia is the bunker system. This system consists of a storage shed where each feed commodity is stored in separate bunkers. Commodities are handled via a front-end loader, which transfers the commodities from the bunker into a truck-mounted mixer feeder (feed truck) (Photograph 12). Each commodity has a pre-determined weight, monitored by load cells mounted on the trucks. Liquid supplements are typically loaded via an overhead piping system, controlled by the operator using a remote control. The load is then mixed and delivered to the appropriate pens. This system is suited to large commercial feedlots of 20,000 head or less and has the advantage of having low investment and maintenance costs. The disadvantage of this system is a reduced control of weighing each commodity (operator factor), inconsistent mixing times due to the variation in speed of loading each commodity, and it creates difficulties for future expansion of feedlot capacity (Holcomb and Klett, 1994). The biggest inefficiency with this system is the time spent running a loader between feed commodities; the time spent waiting for a feed truck, or more commonly, the feed truck/s waiting on the loader.

There have been few previous studies undertaken on the energy consumption of feed delivery systems. Madden (2006) looked at the advantages and disadvantages of two types of feeding systems in terms of efficiency at a Queensland feedlot. These included the bunker management feed delivery system and a dual configuration batch-box feed delivery system. Madden (2006) compared data from before and after the installation of the batch-box system, looking at the litres used per tonne, tonnes delivered per truck and loader hour, and tonnes delivered per labour hour. Williams (2007) investigated the efficiency of the bunker management feed delivery system at a Queensland feedlot whilst Reeves (2007) undertook a similar assessment of a NSW feedlot.

**Photograph 12 - Screw mixer feeder loaded with commodities by a front-end loader**

Madden (2006) found that the diesel consumed by two trucks in feed delivery for the bunker management feed delivery system is in the order of 1 L per tonne of ration delivered. This equates to an energy usage of 38.6 MJ per tonne of ration. Hence, a feedlot feeding 10,000 head with 13.5 kg/head/day will consume approximately 5211 MJ during feed delivery.

Williams (2007) found that approximately 24% of the feed delivery truck activity time is spent loading each feed truck, 35% travelling, 21% unloading, 8% waiting for the next load and 12% stationary mixing. Williams (2007) recorded a diesel consumption of 2.7 L per tonne of ration delivered for the three trucks used in feed delivery and 0.2 L per tonne loaded for the loader. Hence, feed delivery fuel usage will depend on the make, model and age of truck, capacity of truck, efficiency of loading and the feedlot layout. Reeves (2007) found that approximately 26% of the feed delivery truck activity time is spent loading dry ingredients, 40% travelling, 17% unloading, 3% waiting for the next load and 14% loading liquids. Reeves (2007) recorded a diesel consumption of 1 L per tonne of ration delivered for the two trucks used in feed delivery and 0.4 L per tonne loaded for the loader.

*Batch-Box System*

A relatively new method of feed delivery in Australia is the batch-box system, with only three currently installed in the country. This system is similar to the bunker system but it incorporates an additional component, a stationary side-dump batch-box. The side-dump batch-box is hydraulically raised and lowered, powered by an electric motor and controlled via remote control (Photograph 13). The commodities for a batch of feed are loaded from the bunkers into the batch-box via a front-end loader while the feed truck/s are delivering their current load. Once the feed truck/s return, the accumulated feed is dumped into the feed truck in 30 seconds (minimum), reducing the time spent waiting for each individual commodity to be loaded into the feed truck, or the loader waiting for a feed truck to load. A dual configuration batch-box system is commonly used so that while one is tipping, the loader driver can be filling the other batch-box (Batch Box, 2006). The boxes are mounted on a static load cell platform, which potentially improves the loading accuracy due to the stationary nature of the platform, compared with a mobile feed truck (Madden, 2006). Madden (2006) claims the major advantage of the batch-box system is a reduction in loading variability, a faster turnover of trucks, and efficient use of equipment, furthering opportunity to increase feedlot capacity. At 2006 values, the capital outlay for a dual configuration batch-box system is significantly less than for a new Roto-Mix truck and the projected life span is significantly longer (D. Bailey pers. Comm.). In addition, the maintenance requirements of the batch-box system are significantly less than the costs of maintaining mobile equipment such as a truck.

**Photograph 13 - The Batch box System incorporates a side dump box**

Madden (2006) found that the diesel consumed by two trucks in feed delivery with a batch-box feed delivery system is in the order of 0.9 L per tonne of ration delivered, a reduction of 10% when compared with the bunker management system.

*Liquid Commodity Loading*

The loading site of the liquid commodities will vary according to the existing infrastructure and feedlot layout. The liquid commodities are typically loaded via an overhead piping system. This system can be located separately or at the same site as the dry commodities as shown in Photograph 14 (left) or batched in a liquid batcher, which is batched and loaded at a separate loading site to the dry commodities (Photograph 14).

Therefore, the energy usage during feed delivery will depend on a number of factors. These include the management system (bunker, batch-box), equipment utilised (type of truck, number of trucks, capacity of trucks, loader capacity), feed out process (number per day) and feedlot layout.

**Photograph 14 - The liquid commodities may be individually Loaded (left) or Batched (right)**

### 3.2.2 Water supply

The energy usage for supplying water to the feedlot and for reticulation is a direct function of the system design (gravity, pumped), pumping requirements (source of water, pumping head, distance), efficiency of the pumping system and power source (diesel, electric). Water for feedlots can be obtained from a variety of sources including shallow and artesian bores, rivers, creeks, irrigation channels, water harvesting of overland flow into on-farm dams and reticulated pipelines.

There are two types of system designs, gravity feed and reticulated systems. Typically, water from the supply source is stored in a buffer storage for contingency supply reasons. These buffer storages are either above-ground concrete tanks or earthen turkey's nest dams. In most cases, they are located such that they can give gravity-feed water to the feedlot pens (Watts et al. 1994). The pumping requirements are dependent on the volume of water pumped, source of water, distance from feedlot and whether further reticulation pumping is required to deliver water from the buffer storage to the pens.

The pumping efficiency will be dependent on the type of pump chosen for the system and pump wear. If the pumping system is poorly maintained, the energy usage and pumping costs can be increased.


**Photograph 15 - Water supply pump (Left) and Reticulation pump station (Right)**

### 3.2.3 Cattle washing

The energy usage for cattle washing is a direct function of the volume of water used. This will depend on the system design (clean water, recycled), pumping requirements (volume, pressure), efficiency of the pumping system, power source (diesel, electric) and importantly the cleanliness requirements of the cattle and this varies between feedlots.

Typically, cattle wash facilities utilise a two-stage washing process. Firstly, cattle are soaked for a period with high-volume low-pressure clean or recycled water. Cattle are then automatically or manually cleaned with high-pressure clean water.

The pumping efficiency will be dependent on the type of pump chosen for the system and pump wear. Pumping recycled effluent leads to high pump wear rates and relatively short pump life. If the pumping system is poorly maintained, the energy usage and pumping costs can be increased.

Research on cattle washing has concentrated on the effectiveness of various techniques and cleanliness achieved. No published data on the energy consumed during cattle washing is available.


**Photograph 16 - Typical cattle washing process – Soaking (Left) and Pressure cleaning (Right)**

### 3.2.4 Waste management

Maintenance of pen conditions that promote drainage, reduce moisture absorption, minimise odour and reduce pen maintenance expense is one of the most important factors in optimising the performance of cattle in feedlots and minimising environmental issues. In addition, health issues and dags can be reduced with regularly cleaned pens. This can be achieved by careful attention to manure collection or pen cleaning (Lott et al. 1994). To maximise cost efficiency, it is important to know about the problems that can be caused by manure build-up, the physical nature of manure, good pen and lane design, manure harvesting, manure storage, manure disposal and solid waste disposal.

The lack of pen cleaning or manure removal can cause a number of problems from poor cattle performance to pollution problems. Pens which have deep manure can have a detrimental effect on daily weight gains and feed conversion efficiency. Bond et al. (1970) found that deep mud could reduce daily gains by 25 to 37% and feed conversion efficiency by 20 to 33% (Lott et al. 1994). While deep manure can cause problems, so can wet conditions.

Wet conditions can affect animal welfare, as there may be an increase in health problems and cattle comfort levels decline. Matsushima (1990) found that wet muddy conditions increase the incidence of foot problems such as footrot. These wet conditions can also pose an occupational health and safety issue for pen riders. Deep wet manure can also increase odour. Watts et al. (1993) found that wet manure generates 50-100 times more odour than dry manure. Obviously deep manure takes longer to dry therefore the odour tends to be more prolonged when compared to a thin layer of manure in a pen (Lott et al. 1994).

Dry manure also causes problems with the resulting dust causing respiratory problems in the cattle and cannot be compacted into mounds. Therefore, to control the dust it is important to retain some level of moisture in the pens (Lott et al. 1994). While manure build up can cause problems, its physical nature will also have an impact on collection efficiency.

Manure forms a distinct profile in the pens. Typically, a hard crust develops on the surface. Under this, there is a moist plastic layer with a lower bulk density than the layer above and below. The bottom layer is a mixture of pen foundation material (i.e. soil, gravel etc) and manure, which is known as the interface layer and should be very dense and impermeable. This interface layer should prevent leaching from the manure profile into the soil. A break in this layer may allow infiltration to occur causing pollution of the ground water (Lott et al. 1994). In addition, this soft floor will reduce foot soreness in the cattle. It is recommended that 25-50 mm of manure is left on the pen floor. Therefore, care needs to be taken to ensure this interface layer is not damaged when pen cleaning is being completed (Lott et al. 1994).

In recent years, some lot feeders have chosen to remove all manure, including the interface layer, from pens. There can be several reasons for this management choice. Complete manure removal minimises odour issues. In feedlots located in a winter-dominant rainfall zone, complete manure removal prior to winter allows for better pen conditions during winter. If this practice is followed, the underlying pen surface needs to be thoroughly compacted and levelled.

The moisture content of the manure also plays an important role when cleaning pens. The correct moisture content is important because if the manure is too wet, it becomes too difficult to handle and cleaning is very slow. The same can be said when the pens are dry and the surface becomes extremely hard and difficult to remove, which may require a shallow ripping process to break up the hard layer adding further cost to the manure collection process.

Therefore, the ideal time to clean the pens is when the manure is moist but not wet, which can easily be cut or scraped from the bottom of the pens but this will depend on a combination of environmental and operational factors (Lott et al. 1994). The frequency of pen cleaning will depend on manure accumulation and once again the operational and environmental management of the feedlot. Manure accumulation rates will depend on the animal size and stocking density (Watts 1991).

The design of the feedlot and, in particular, the pens will influence the ease and method of manure removal. Factors that will affect this include the foundation material and pen surface, pen size and shape, stocking density, fence construction, location and design of feed and water troughs, location and design of shade structures, access into the pens, manure distribution system and manure removal machinery (Lott et al. 1994).

The pen size and shape will determine the type of machinery can be used to clean the pens. For ease of manure removal, the minimum pen size should be 25 metres across and at least 30 metres deep. Pens this size will still limit certain machinery from being used. Both the width of the fence panels and height of bottom cable are important in pen cleaning because the manure accumulates under fence lines and therefore machinery needs access to be able to clean the manure. Therefore, panel width needs to be at least 3 metres and 400 mm is required between the bottom rail or wire and the pen surface (Lott et al. 1994).

High traffic areas around the feed and water troughs are subject to greater wear and tear than other parts of the pen. It is recommended that there is a concrete apron around the water trough and along the feed bunk being at least 3 metres wide. Narrow aprons can cause problems for machinery when cleaning the pens.

The last issue in the design features of pens is the access. Manure collection and transport machinery must be able to freely enter, manoeuvre within and depart from each pen. The configuration of fence lines and gates at the bottom of the pens affects stock and machinery access into pens (Lott et al. 1994). Pen design features are obviously done at the building stage and little can be done once completed, not like the manure distribution system which is where the real cost savings can be made.

Butchbaker et al. (1971) reported that solid manure handling costs for a 20,000 head South-western USA feedlot were approximately 12% of the total feedlot operating expense. Similarly, Park (1972) found that manure collection and handling costs accounted for 11.7%of the total operating costs of a 22,000 head feedlot in Oklahoma. The management of manure involves four key processes including harvesting and removal from pens, storage and spreading. These processes can be completed in a number of different ways and different combinations. Each distribution system has benefits and disadvantages.

All manure distribution systems start with the pen cleaning operation. The collected manure can either be directly spread or stored in a stockpile prior to spreading. The storage can either be a temporary stockpile such as an in pen mound, removal to a common stockpile at the feedlot or removal to a stockpile at the site where it is to be spread (Lott et al. 1994).

Butchbaker et al. (1971) found that investment and operation cost of solid manure handling systems varied with feedlot size, manure handling distance and equipment usage. The costs involved in collecting the manure reduced as equipment usage increased 25 to 100 days per year (Sweeten & Reddell 1979).

A range of equipment is used within feedlots such as elevating scraper, grader, box scraper, wheel loader, dozer and bobcat for the pen cleaning activity. Trucks of all shapes and sizes are used to cart the manure from the pens.

Not all types of the equipment are suitable for every feedlot. The main criteria for equipment selection are the size of the pens, pen access and laneway access. Climate can also determine the type of machinery that can be used. For example, the mild summers and cold wet winters in southern Australia means that the machinery needs to be able to operate in wet boggy conditions.

Elevating scrapers can only be used in a feedlot with large pens being a minimum of 50 x 50 metres. The scraper should be fitted with a cutting edge rather than rippers and they are unable to clean in certain areas of the pen such as corners, under and along fences as well as water and feed troughs. A wheel loader or bobcat would be needed in conjunction with the elevating scraper to clean the areas that are inaccessible to the elevating scraper.

Graders are an option but are rarely used in Australia. Once again, a larger pen size is required, but provide good control over the depth of cut and provide a smooth finish.

The most commonly used equipment in Australia for medium to large feedlots is a combination of box scraper and tractor, and bobcat or front-end loader for manure removal. The box scraper and tractor scrape the manure from the pen and mound it into the middle of the pen. The box scraper and tractor combination is compact, manoeuvrable, has good depth control and gives a smooth finish to the pen surface. This system can be done by a single operation and is normally faster rate of cleaning. The bobcat is typically used to clean under fences and aprons. A front-end loader is used to remove manure from the pens. In some facilities, a loader is used to clean the aprons and under fences (Lott et al. 1994).

Front-end loaders or wheel loaders are required for some components of the manure collection and removal operation in all but the very small feedlots. Front-end loaders are able to collect and remove manure in the same operation and at a faster rate than a box-scraper tractor combination. However, using the loader can result in damage to the interface layer because of the lack of control over the bucket height (Lott et al. 1994).

While bulldozers can be used, they are not recommended because the damage the tracks cause to the surface of the pens. A bulldozer can cut and push the manure into mounds. However, the lack of depth control and skid-steering will impact the interface layer (Lott et al. 1994).

Pen size and shape, pad moisture and depth as well as machinery type and operation have a large influence on operating efficiency. Collection rates of manure are influenced by environmental conditions and management factors. The level of moisture and the current state of biological decomposition will affect the amount of manure removed.

In-pen mounds are commonly used for the temporary storage of manure because the mounds give a number of benefits or flexibility in the harvesting operation. These include the *in-situ* decomposition of manure in the mound and thus a reduction in the mass to be removed from the pen. The removal of the manure can take place at more convenient times and the manure collection can occur when required rather than when transport and removal machinery are available (Lott et al. 1994). In-pen mounding is used in a number of feedlots to reduce harvesting rates by up to 38 percent (Lott et al. 1994). While this practise enables timely pen scraping and improved removal efficiency, it has little impact on the cost of gathering the manure (Lott et al. 1994).

There is very little published work on the efficiency of various feedlot manure collection systems. Sweeten and Reddell (1979) undertook time and motion studies to evaluate machine productivity, energy consumption and cost of feedlot manure collection at four Texas cattle feedlots.

**Photograph 17 – PTO-driven compost windrow turner**

**Photograph 18 – Screening machinery at manure stockpile**


**Photograph 19 – Manure spreading machinery**

Sweeten and Reddell (1979) suggests that the efficient collection of feedlot manure can mean savings for cattle feedlot operators and profit for manure contractors who sell manure for fertiliser, therefore manure handling to be profitable, time, energy and equipment costs must be controlled.

The specific objective of the study by Sweeten and Reddell (1979) was to compare alternate manure collection systems based on machine productivity, energy consumption and cost. They also evaluated the productivity, cost and operator performance for loading manure trucks and determined the time required to haul and spread manure. The study looked at the use of an elevating scraper, wheel loader, wheel loader with the surface prepared with a roto-tiller and a wheel loader with the surface prepared with a chisel-plough.

Sweeten and Reddell (1979) found that the wheel loader / chisel-plough combination had the highest collection rate of 160 tonnes per hour at 100 percent operator efficiency. This was followed by the elevating scraper, wheel loader, and the wheel loader / roto-tiller combination. The most energy efficient collection system was the elevating scraper.

**Table 1 - Time-motion study of feedlot manure collection systems**

| Feedlots | Primary collection machine | Feedlot surface preparation | Finishing steps required | No. pens studied | Manure collection rate at 100 percent efficiency, t/h | Energy requirements at 100 percent efficiency, kWh/t | Collection cost, $/t |
|---|---|---|---|---|---|---|---|
| A | Elevating scraper | None | Wheel loader to clean pen corners | 4 | 114 | 0.88 | 0.21 |
| B | Wheel loader | Rototilled | None | 1 | 106 | 0.99 | 0.19 |
| C | Wheel loader | None | None | 1 | 107 | 1.28 | 0.23 |
| C & D | Wheel loader | Chisel-plowed 3 times | None | 4 | 160 | 0.96 | 0.20 |

(Source: Sweeten & Reddell 1979).

Reeves (2007) evaluated the efficiency of the manure collection system at a NSW and QLD feedlot in a time and motion study. Reeves (2007) calculated energy requirements per tonne of manure collected. A number of equipment combinations were used within each manure collection system. Reeves (2007) found that diesel fuel usage ranged from 0.35 to 0.60 L per tonne of manure. Therefore, the energy usage during manure collection will depend on a number of factors. These include the management system (mounding in pens, direct to stockpile), equipment utilised (excavator, scraper, loader, trucks, equipment number and equipment capacity) and cleaning frequency.

In addition to removal of manure from pens, there is additional energy usage in manure handling. This can include windrow composting of manure (PHOTOGRAPH 17), screening of stockpiled manure (PHOTOGRAPH 18) and then spreading of manure in the fields (PHOTOGRAPH 19).

### 3.2.5 Administration

Energy plays a vital role in the administration and operation of feedlots. Administration energy usage has been defined as that used in office facilities, staff amenities and for operation of staff vehicles around the facility. Office facilities use energy for many purposes including heating and cooling, lighting, hot water, office equipment (computers, faxes, photocopiers, etc.) and weighbridge.

Staff amenities use energy in lighting, refrigeration, cooking, hot water, heating and cooling and sundry uses. Transport of staff around the feedlot is an important component of administration energy usage.

Lipper et al. (1976) reported that administration consumed approximately 5.6% of the total energy requirement of Kansas feedlots. Increased heating costs in winter may be a plausible explanation for the high percentage use.

### 3.2.6 Repairs and maintenance

Energy is also consumed in repairs and maintenance activities around the feedyard. The majority of feedlots have a workshop facility, which does minor repairs to vehicles, mechanical equipment and infrastructure. The size and capability of the workshop is dependent on the location of the feedlot from a major retail centre. Repairs and maintenance has been defined as that used in workshop facilities and mobile plant used for road maintenance etc.

**Photograph 20 - Water truck for road maintenance and dust suppression**

## 3.3 Indirect energy usage

The energy or fuel consumed for transport of incoming and outgoing cattle can be significant and depends upon the types of vehicles used, fuel type/s, fuel efficiency, distance travelled and loading capacity. Most feedlots are located within a couple of hundred kilometres of abattoirs. However, incoming cattle can be sourced from sites thousands of kilometres away, especially for vertically integrated corporate feedlots.

Fuel efficiency in transport vehicles is measured by fuel usage over a set distance, traditionally litres of fuel per 100 kilometres travelled. Vehicle fuel consumption is a function of the efficiency of vehicle weight, vehicle motor technology, fuel technology and other factors. An ongoing interest in reducing transportation energy use has resulted in a continuing focus on fuel efficiency. Vehicle weight reductions and advances in technology have led to improvements in truck fuel efficiency.

### 3.3.1 Livestock transport

Heavy vehicles over 10 tonnes gross vehicle mass (GVM) are predominantly used to transport livestock. These vehicles use turbocharged, four stroke compression ignition engines commonly referred to as 'diesel engines'. PHOTOGRAPH 21 illustrates a typical semi trailer livestock transport with two decks.

**Photograph 21 - Typical semi trailer (2 decks) livestock transport**

### 3.3.2 Commodity delivery to the feedlot

The energy, or fuel, consumed for transport delivery of feed commodities depends upon the vehicle type, fuel used, fuel efficiency, loading efficiency and distance travelled. Diesel powered vehicles are mainly used for the transport of commodities.

Vehicle loading efficiency can vary greatly between commodity types, with straws and roughages being volume limited and grains and molasses being mass limited. PHOTOGRAPH 22 illustrates a semi trailer unloading grain.

**Photograph 22 - Semi trailer unloading grain**

### 3.3.3 Manure removal from the site

Removal of manure off-farm is also an indirect energy consumer. This process may be undertaken by the feedlot operator or by independent contractors. The energy efficiency of manure transport depends upon the truck type and fuel efficiency, the distance travelled and the volume and dry matter content of the manure. Stockpiling of manure pre-transport, either in the pen or in a designated stockpile area, reduces its moisture content and thus the volume of manure for transportation. However, no data was collected in this project on this component.

# 4 Materials and Methods

## 4.1 Overview – experimental work

The objective of the project was to collect good-quality data on energy usage and relate this to production parameters in feedlots so that the information could be used across Australia. To that end, it was necessary to ensure that the feedlots involved were representative and that reliable data could be obtained. The steps in the project were:

1. Select a range of feedlots across Australia that were representative of climatic zones, feeding regimes, management styles and cattle markets.
2. Review the design and management of these feedlots to select those where reliable data could be collected at a reasonable cost.
3. Select the preferred feedlots and complete negotiations at each site.
4. Design an instrumentation system for each feedlot.
5. Design a data collection system for each feedlot.
6. Undertake regular (monthly or fortnightly) data collection.
7. Undertake short-term detailed data collection for specific aspects of water usage.
8. Analyse and review the data.

## 4.2 Selected feedlots

Following a lengthy process, eight feedlots were selected to provide a representative sample. TABLE 2 summarises the key characteristics of the selected feedlots. To maintain confidentiality, none of the feedlots are identified by name and will be referred to as Feedlots A to H.

The selected feedlots provide a range of climatic conditions from a northern feedlot in a hot, humid summer-dominant rainfall to southern feedlots in cooler, winter-dominant rainfall zones.

FIGURE 2 and FIGURE 3 shows the mean monthly temperatures and monthly rainfall probabilities for Feedlot A respectively. Feedlot A is considered to have a strongly summer-dominant rainfall with a reasonable probability of high rainfall in some months. It has warm to hot summers and mild winters. In summer, the maximum monthly temperatures range from 33 to 35°C. During winter, average maximum monthly temperatures range from 22 to 26°C with monthly minimum temperature around 8 to 9°C.

FIGURE 4 and FIGURE 5 shows the mean monthly temperatures and monthly rainfall probabilities for Feedlot H respectively. Feedlot H is considered to have a winter-dominant rainfall and much lower than Feedlot A. It has mild to warm summers and cool to cold winters. In summer, the maximum monthly temperatures range from 27 to 30°C. During winter, average maximum monthly temperatures range from 13 to 15°C with monthly minimum temperature around 4 to 6°C.

Grain processing methods vary from simple tempering to reconstitution and steam flaking. Some feedlots wash cattle (mainly in winter) while other feedlots do not undertake any cattle washing.

Feedlot D was not included in the water studies and Feedlot C was not included in the energy studies.

**Table 2 – Characteristics of selected feedlots**

| Feedlot Name | | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|
| **Climate** | | | | | | | | | |
| Mean Annual Rainfall | mm | 577 | 582 | 403 | 641 | 679 | 831 | 640 | 716 |
| Rainfall Pattern | | Summer dominant | Winter dominant | Winter dominant | Summer dominant | Summer dominant | Uniform | Summer dominant | Summer dominant |
| Mean Annual Class A Pan Evaporation | mm | 2372 | 1825 | 1788 | 1934 | 1934 | 1423 | 1934 | 1715 |
| Mean Max Temp – January | °C | 34.1 | 31.2 | 29.6 | 31.6 | 31.6 | 25.9 | 31.6 | 29.7 |
| Mean Min Temp – June | °C | 8.9 | 2.7 | 4.3 | 5.7 | 5.7 | 2.0 | 5.7 | 4.6 |
| **Feedlot Capacity and Design** | | | | | | | | | |
| Licensed Capacity | head | >15000 | >15000 | >15000 | >15000 | >15000 | >15000 | >5000 | >1000 |
| Cattle Washing | % of turnoff | 0 | 30 | 40 | 0 | 10* | 40 | 0 | 65 |
| **Feed Processing** | | | | | | | | | |
| Grain Processing Method | | Steam Flaked | Steam Flaked | Steam Flaked | Reconstitution | Reconstitution | Steam Flaked | Steam Flaked | Tempering |
| Main Energy Source | | LPG | Natural Gas | LPG | Electricity | Electricity | Butane | LPG | Electricity |

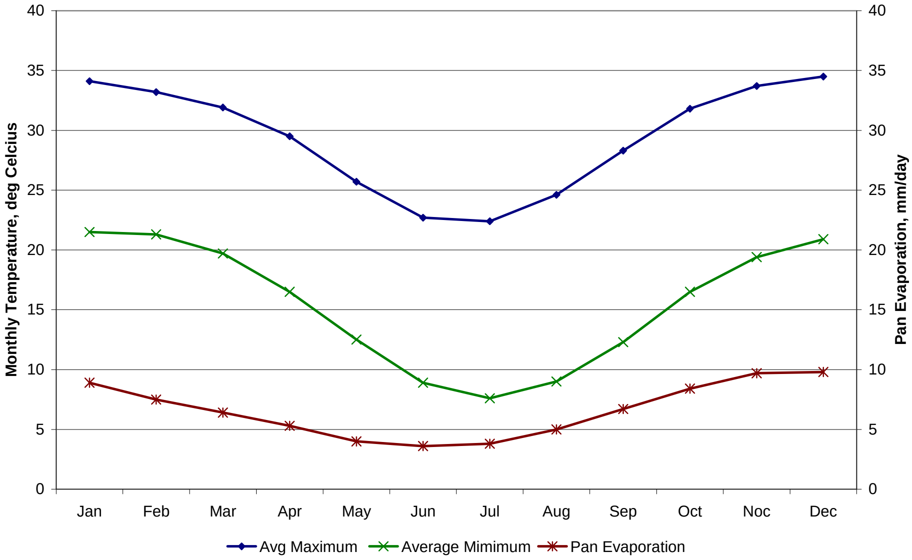



**Figure 2 - Average monthly temperatures and pan evaporation for Feedlot A**

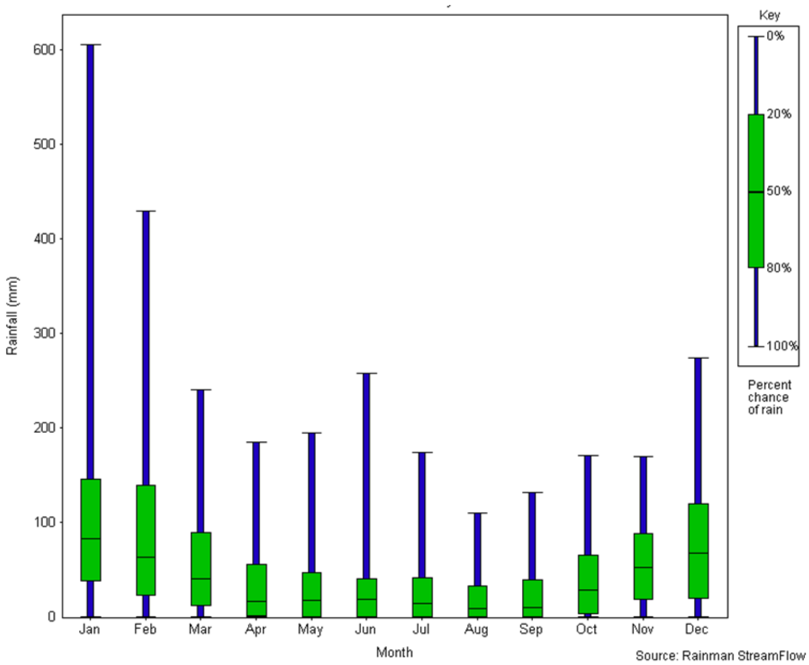



**Figure 3 - Monthly rainfall probabilities for Feedlot A**

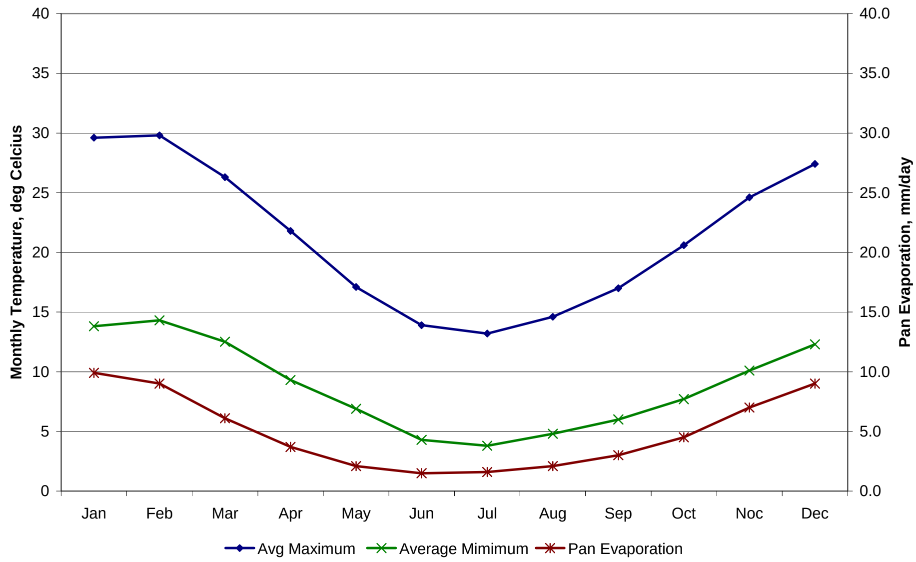



**Figure 4 - Average monthly temperatures and pan evaporation for Feedlot H**

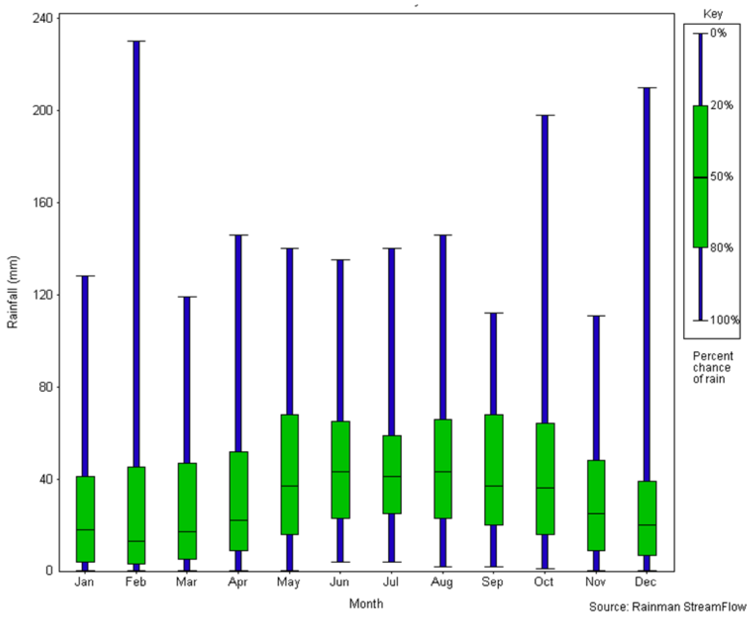



**Figure 5 - Monthly rainfall probabilities for Feedlot H**

## 4.3 Energy supply network

As part of the selection process, the energy supply network at each feedlot was inspected and a flow chart prepared. FIGURE 6, FIGURE 7, FIGURE 8, FIGURE 9, FIGURE 10, FIGURE 11 and FIGURE 12 show the energy supply networks for Feedlots A, B, D, E, F, G and H respectively. Feedlot C did not participate in the energy usage studies.

The project needed to be able to measure total energy usage at each feedlot (Focus Area 1 on each energy supply network), the direct energy usage in the main feedlot activities and indirect energy usage. The main areas of interest were:

1. Focus Area 2 - Water Supply
2. Focus Area 3 - Feed management - Processing & Delivery
3. Focus Area 4 - Waste management - Pen cleaning, manure stockpiling, effluent irrigation
4. Focus Area 5 - Cattle Washing
5. Focus Area 6 - Administration

Energy sources include electricity, diesel, petrol and gas (e.g. LPG, butane etc). Usage of diesel, petrol and gas are typically available from existing fuel bowser and gas meters. In most cases, electricity is provided by overhead supply to a main switchboard then distributed internally throughout the feedlot. Therefore, total feedlot electricity usage can be easily recorded from onsite power authority metering. However, electricity usage by individual activities or components within activities cannot be easily determined without installation of power metering on the individual supply.

During the feedlot inspection, existing metering was located. This included reviewing electricity, fuel and gas metering. In all cases fuel and gas metering was adequate. The required positioning of any additional power meters for electricity usage was determined.

A gap analysis was undertaken to determine the quantity and type of power measurement instrumentation required to allow direct or indirect measurement of the major activities. This was undertaken in collaboration with the Condamine Electric Company (CEC), a company that specialises in industrial power installations.

## 4.4 Energy supply network instrumentation

A local company, Condamine Electric Company (CEC), in consultation with FSA Consulting, selected a number of power meters to suit the type of installation. The selection parameters included the size (amperage) of the sub-main, cable size, current transformer (CT) size, type and quantity, mounting requirements (surface, panel, enclosure) and ease of installation. Power meters and associated switchgear were selected that best suited the individual installation and that were widely in use.

CEC undertook a site visit to each feedlot and installed the power meters. This ensured a coordinated, standardised and timely installation of the instrumentation. Two types of power meters were selected. These included the IME NEMO 72-L and the IME CONTO 43. The following sections provide a brief overview of the specifications and capabilities of each type of power meter and associated switchgear.

### 4.4.1 IME NEMO 72-L power meter

The IME NEMO 72-L (PHOTOGRAPH 23) is a programmable network monitor that can monitor single-phase (50-290v) or three-phase (80-500v) networks. The unit is provided in a self-extinguishable polycarbonate enclosure 72 mm (wide) x 72 mm (breadth) x 75 mm (depth) and is flush mounted on the switchboard panel. All of the main quantities of a three-phase network are measured including voltage (phase and linked), current (phase and neutral), power (phase and three-phase active), power factor, frequency and working hours and minutes. These measurement quantities are displayed on different key activated pages on the backlit LCD. The unit has a reading accuracy for voltage (v), current (a), power (kWh) of ± 0.5%, power factor ± 2% and frequency of ± 0.2 Hz. The unit is connected to the respective supply with dedicated CT. The unit also has a programmable pulse output and RS485 communication for control and logging capabilities.


**Photograph 23 - IME NEMO 72-L power meter**

### 4.4.2 IME CONTO D4-S power meter

The IME CONTO D4-S (PHOTOGRAPH 24) is a programmable three-phase (190-440v) network monitor. The unit is provided in a sealable self-extinguishing polycarbonate housing and terminal block 72 mm (wide) x 89 mm (breadth) x 60 mm (depth) and is typically mounted on a 35 mm DIN rail inside the switchboard panel. Partial and total power, power demand and power maximum demand of a three-phase network are measured. These measurement quantities are displayed on different push-button activated pages on the backlit LCD. The unit has a reading accuracy for power (kWh) of ± 1%. The unit is connected to the respective supply with dedicated CT. The unit also has a programmable pulse output and RS485 communication for control and logging capabilities.


**Photograph 24 - IME CONTO D4-S power meter**

### 4.4.3 Associated equipment – current transformer (CT)

To facilitate the safe measurement of large currents, a current transformer (CT) was also installed on each phase circuit of the power meter. The circuit is largely unaffected by the insertion of the CT. A CT is a type of instrument transformer designed to provide a current in its secondary winding proportional to the alternating current flowing in its primary. The CT safely isolated the measurement circuitry from the high voltages typically present each circuit being measured. The secondary winding for all CT used in this work was 5 amperes. For example, a 100/5 CT provides an output current of 5 amperes when the primary was passing 100 amperes.

**Photograph 25 - Typical installed current transformers**

### 4.4.4 Feedlot A instrumentation

At Feedlot A, there is an overhead electricity supply to the water pumping system, feedmill, office, induction/stables and hospital complexes. Each overhead supply has associated power authority metering. At this facility, the power supply for the workshop and vehicle washing activities is sourced from the feedmill supply. Therefore, only one new power sub-meter was required to allow the usage of the workshop and vehicle washing activities to be measured. This meter was located to sub-meter the power usage for the workshop and vehicle washing activities. The selected meter was a CONTO D4-S (See PHOTOGRAPH 26) and was installed within a dedicated enclosure, surface mounted on the workshop meter board. The meter was installed with 100/5 CT and three circuit break fuses mounted in the enclosure.

**Photograph 26 - Installed power meter E6 at Feedlot A**

There was no requirement to install flow meters to the diesel/petrol bowsers as existing meters were installed. Similarly, an existing gas meter recorded the usage of LP gas.

### 4.4.5 Feedlot B Instrumentation

At Feedlot B, there is an overhead electricity supply to two of the three water supply bores and to the facility's main switchboard. From the main switchboard, electricity is distributed to a number of activities via a series of aerial sub-mains. Therefore, a number of new power sub-meters were required to monitor usage levels in the required focus areas. New power meters were installed on the grain movement, tub grinder, roller mills, cattle wash bay, office/workshop and water supply bore sub-mains.

The selected meters (see PHOTOGRAPH 27 and PHOTOGRAPH 29) for the grain movement (E2), tub grinder (E3), roller mills (E4) and liquid supplements (E10) metering was a NEMO 72-L. These were mounted on the front panel of the main switchboard. Each meter was installed with appropriately sized CT of 300/5 for the tub grinder and 200/5 for the grain movement and the roller mills. Each meter had three associated circuit break fuses mounted in the switchboard.

The selected meters (see PHOTOGRAPH 28) for the water supply bore (E5, E9), cattle wash (E7) and office/workshop (E8) was a CONTO D4-S. Each meter was installed within a dedicated enclosure, surface mounted on the respective complex meter board. Each meter was installed with appropriately sized CT of 100/5 for the water supply bore, and 80/5 for the office/workshop and 50/5 for the cattle wash bay. Each meter had three associated circuit break fuses mounted in the enclosure.

There was no requirement to install flow meters to the diesel/petrol bowsers as existing meters were installed.


**Photograph 27 - Installed power meters E2, E3 and E4 at Feedlot B**


**Photograph 28 - Installed power meters E5, E7 and E8 at Feedlot B**


**Photograph 29 - Installed power meters E9 and E10 at Feedlot B**

### 4.4.6 Feedlot D instrumentation

At Feedlot D, there is an overhead electricity supply to the three of the four bore water supply pumps and to the facility's main switchboard. From the main switchboard, electricity is distributed to a number of activities via a series of aerial sub-mains. Therefore, a number of new power sub-meters were required to monitor usage levels in the required focus areas. New power meters were installed on the office, roller mills, tub grinder, grain movement, stationary mixer/batch boxes, workshop, bore water supply pump, grain pad and water reticulation pumps.

The selected meter for the office (E6), grain movement (E6), tub grinder (E9), roller mills (E8), stationary mixer/batch boxes (E10 & E15) and workshop (E16) metering was a NEMO 72-L (see PHOTOGRAPH 30). These were mounted on the front panel of the main switchboard or sub-main switchboards. Each meter was installed with appropriately sized CT of 300/5 for the tub grinder, 200/5 for grain movement, roller mills and stationary mixer, 150/5 for the workshop and 50/5 for the office. Each meter had three associated circuit break fuses mounted in the switchboard.

The selected meter for the water supply bore (E13), reticulation pumps (E11 and E12) and grain pad (E14) was a CONTO D4-S. Each meter was installed within a dedicated enclosure, surface mounted on the respective complex meter board (See PHOTOGRAPH 31 and PHOTOGRAPH 32). Each meter was installed with appropriately sized CT of 50/5 and each meter had three associated circuit break fuses mounted in the enclosure.

**Photograph 30 - Installed power meters E6, E7, E8 (Left) and E9, E10, E15, E16 (Right) at Feedlot D**

**Photograph 31 - Installed power meters E11 and E12 at Feedlot D**

**Photograph 32 - Installed power meters E13 and E14 at Feedlot D**

### 4.4.7 Feedlot E instrumentation

At Feedlot E, there is an overhead electricity supply to the water supply and irrigation bores and to the facility's main switchboard. From the main switchboard, electricity is distributed to a number of activities via a series of sub-mains. Therefore, a number of new power sub-meters were required to monitor usage levels in the required focus areas. New power meters were installed on the Grain movement and Induction/Hospital and water supply bore sub-mains. The office/workshop usage was obtained by deduction.

PHOTOGRAPH 33 shows the four power meters installed at Feedlot E. The selected meters for grain storage and movement (E5 and E6) and Induction/Hospital (E7) metering was a CONTO D4-S. These were mounted on the front panel of the main switchboard. The meters were installed with an appropriately sized 80/5 CT and three associated circuit break fuses per meter mounted in the switchboard.

The selected meter for the water supply bore (E4) was a CONTO D4-S. Meter E4 was installed within a dedicated enclosure, an appropriately sized CT of 50/5 and three associated circuit break fuses mounted in the enclosure.


**Photograph 33 - Installed power meters E4, E5, E6 and E7 at Feedlot E**

### 4.4.8 Feedlot F instrumentation

At Feedlot F, there is an overhead electricity supply to the water supply pump, induction and cattle wash complex and to the facility's main switchboard. From the main switchboard, electricity is distributed to a number of activities via a series of aerial sub-mains. Therefore, a number of new power sub-meters were required to monitor usage levels in the required focus areas. New power meters were installed on the workshop, office, induction, stables, water treatment plant and diesel bowser. The grain movement and feed processing usage was obtained by deduction.

The selected meter for the workshop (E7), diesel bowser (E6) and office aerials (E4) was a NEMO 72-L (see PHOTOGRAPH 34). These were mounted on the front panel of the main switchboard. Each meter was installed with appropriately sized CT of 150/5 for the office aerials and 100/5 for the workshop and diesel bowser. Each meter had three associated circuit break fuses mounted in the switchboard.

The selected meter for the office (E9), stables (E5), induction (E8) and treatment plant (E10) was a CONTO D4-S (see PHOTOGRAPH 35). Each meter was installed within a dedicated enclosure, surface mounted on the respective complex meter board. Each meter was installed with appropriately sized CT of 150/5 for the office, 80/5 for the stables and 50/5 treatment plant and for induction. Each meter had three associated circuit break fuses mounted in the enclosure.


**Photograph 34 - Installed power meters E4, E5, E6 and E7 at Feedlot F**


**Photograph 35 - Installed power meters E8, E9 and E10 at Feedlot F**

### 4.4.9 Feedlot G instrumentation

At Feedlot G, there is an overhead electricity supply to the water supply bore, Induction, Hospital and to the facility's main switchboard. From the main switchboard, electricity is distributed to a number of activities via a series of aerial sub-mains. Therefore, a number of new power sub-meters were required to monitor usage levels in the required focus areas. New power meters were installed on the water supply/reticulation pumping system, cattle wash bay, workshop and old mill/office sub-mains. The selected meter for the old mill/office (E7), cattle wash bay (E9) and workshop (E10) was a NEMO 72-L. These were mounted on the front panel of the main switchboard (see PHOTOGRAPH 36). Each meter was installed with appropriately sized CT of 100/5 for the old mill/office and 100/5 for the cattle wash and workshop. Each meter had three associated circuit break fuses mounted in the switchboard. The selected meter for the water supply/reticulation pumping system (E8) was a CONTO D4-S. The meter was installed within a dedicated enclosure, surface mounted on the complex meter board (see PHOTOGRAPH 36). The meter was installed with an appropriately sized CT of 80/5 and three associated circuit break fuses mounted in the enclosure.


**Photograph 36 - Installed power meters E7, E8, E9 and E10 at Feedlot G**

### 4.4.10 Feedlot H instrumentation

At Feedlot H, there is an overhead electricity supply to the bore water supply pumps, hospital/stables and to a main switchboard at the feedmill. From the main switchboard, electricity is distributed to a number of activities via a series of aerial sub-mains. Therefore, a number of new power sub-meters were required to monitor usage levels in the required focus areas. New power meters were installed on the feedmill, tub grinder, office, cattle wash, induction/hospital, workshop and water reticulation pump.

The selected meter for the feedmill (E4), tub grinder (E5), office and weighbridge (E8), cattle wash (E7) and induction/hospital (E6) was a NEMO 72-L. These were mounted on the front panel of the main switchboard or at the respective complexes meter board (see PHOTOGRAPH 37 and PHOTOGRAPH 38). Each meter was installed with appropriately sized CT of 400/5 for the feedmill, 300/5 for the tub grinder, 200/5 for the cattle wash pumps and office, 150/5 for the workshop and 100/5 for induction/hospital. Each meter had three associated circuit break fuses mounted in the switchboard.

The selected meter for the water reticulation pump (E10) was a CONTO D4-S. This meter was installed within a dedicated enclosure, surface mounted on the pump meter board See PHOTOGRAPH 38). The meter was installed with an appropriately sized CT of 80/5 and had three associated circuit break fuses mounted in the enclosure.


**Photograph 37 - Installed power meters E4, E5 and E8 at Feedlot H**

**Photograph 38 - Installed power meters E6, E7 and E10 at Feedlot H**

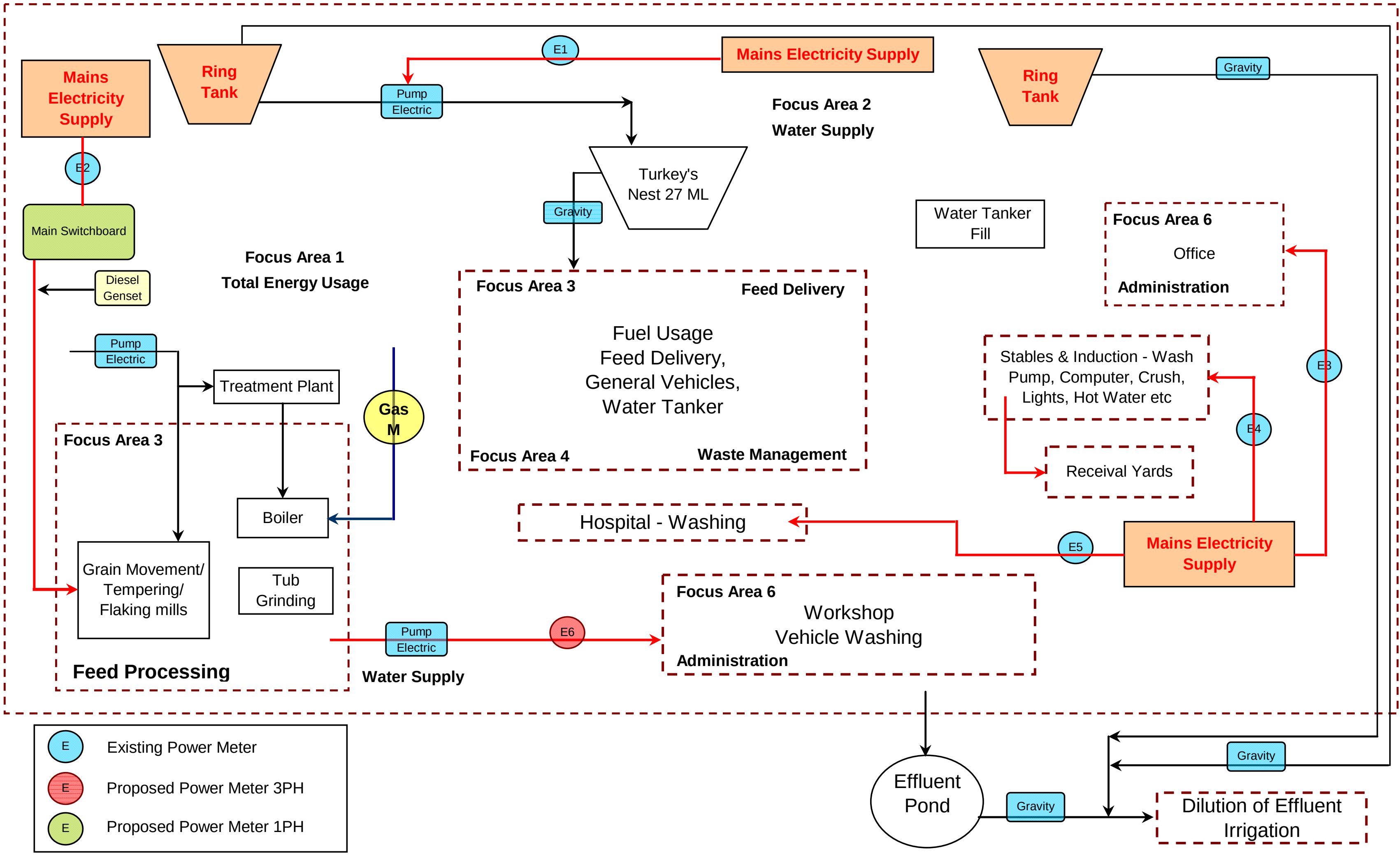



**Figure 6 - Energy supply network – Feedlot A**

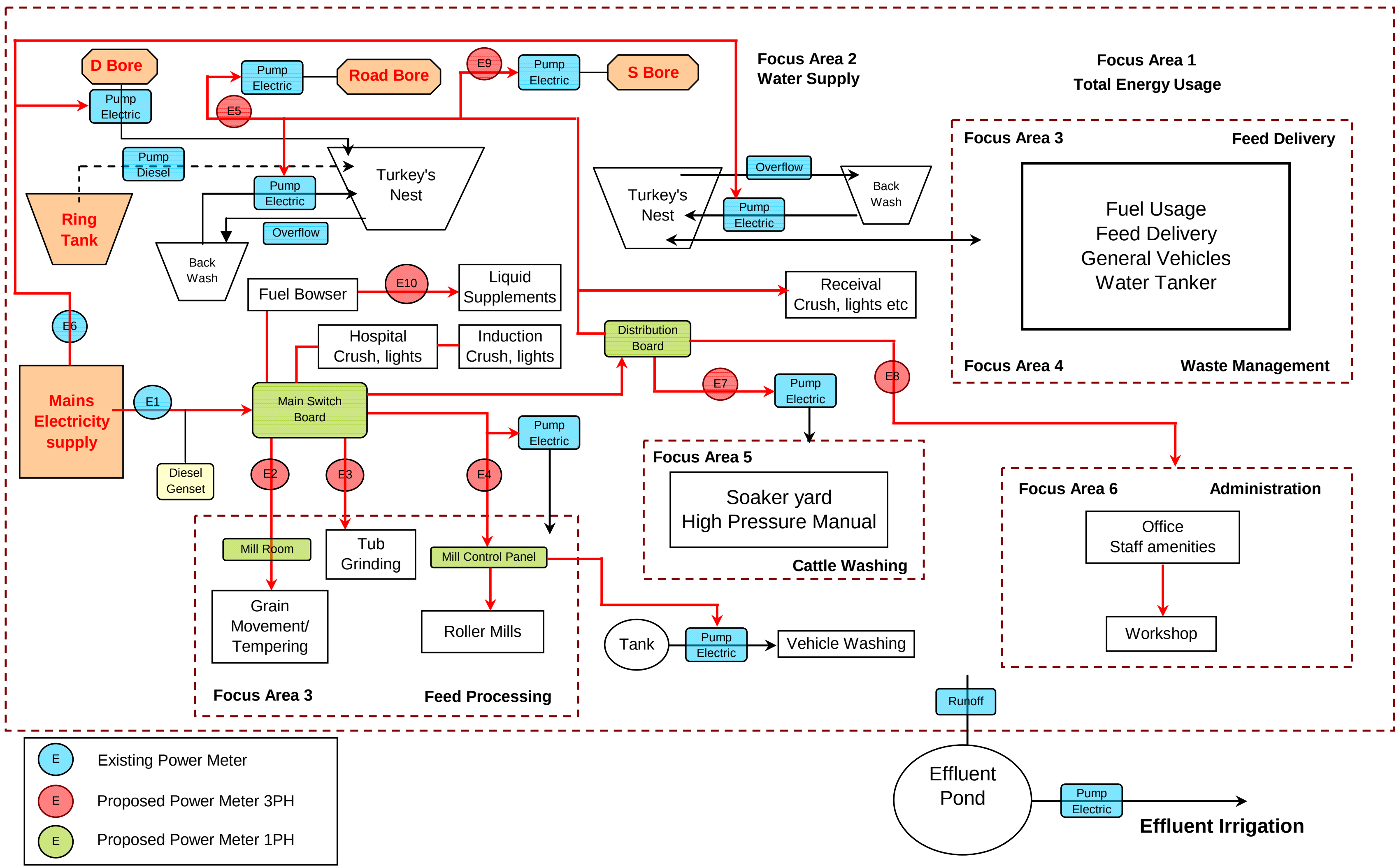



**Figure 7 - Energy supply network – Feedlot B**

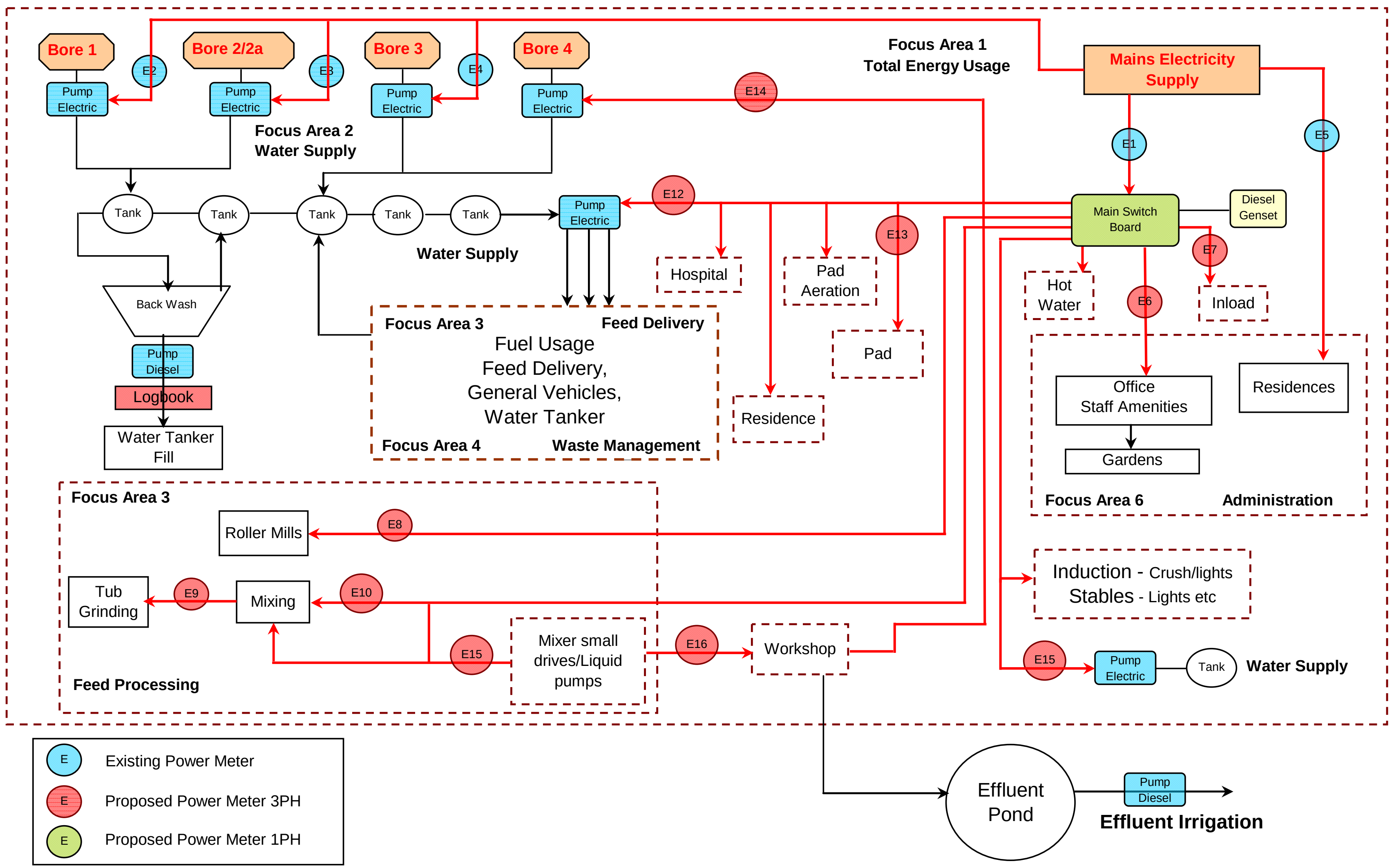



**Figure 8 - Energy supply network – Feedlot D**

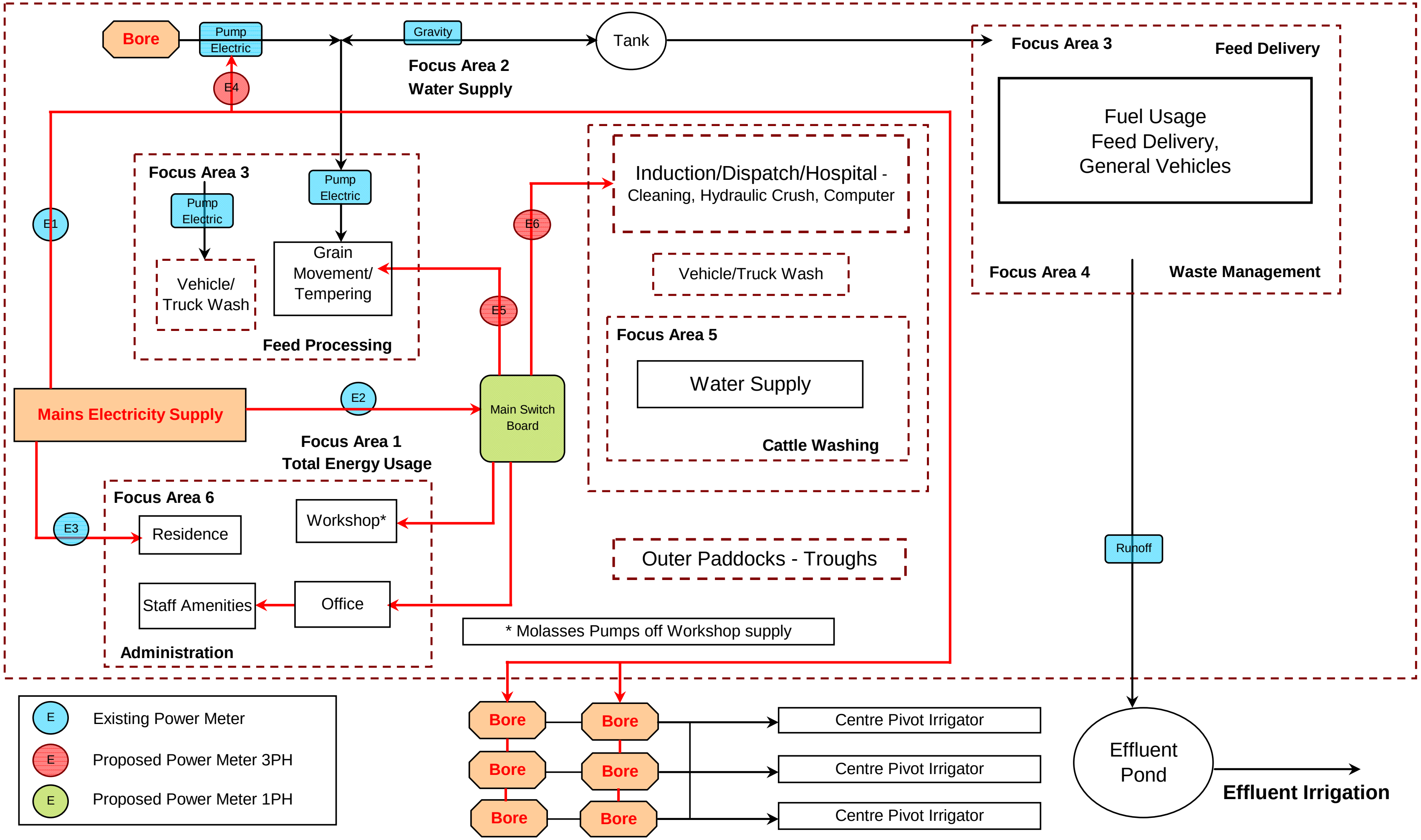



**Figure 9 - Energy supply network – Feedlot E**

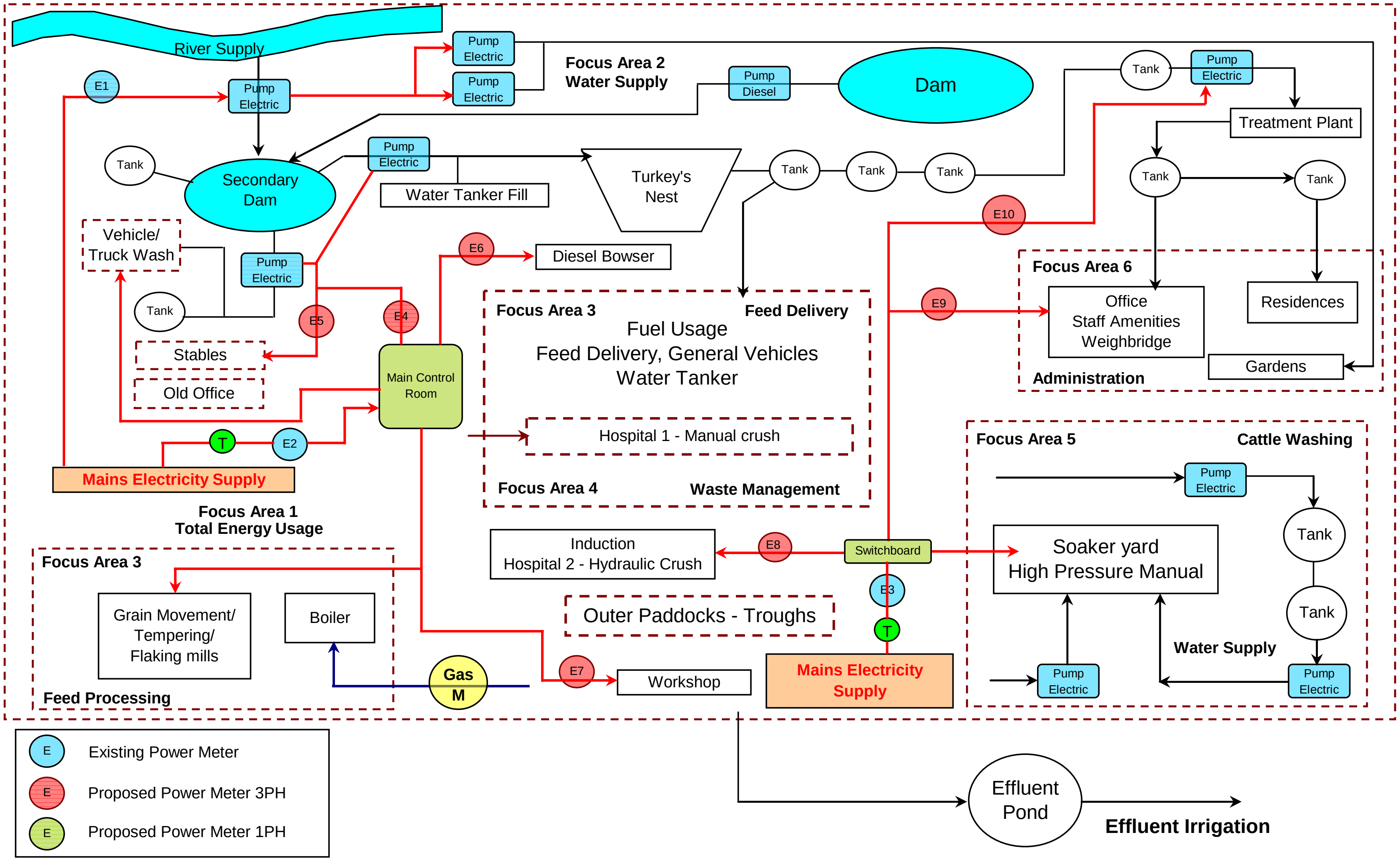



**Figure 10 - Energy supply network – Feedlot F**

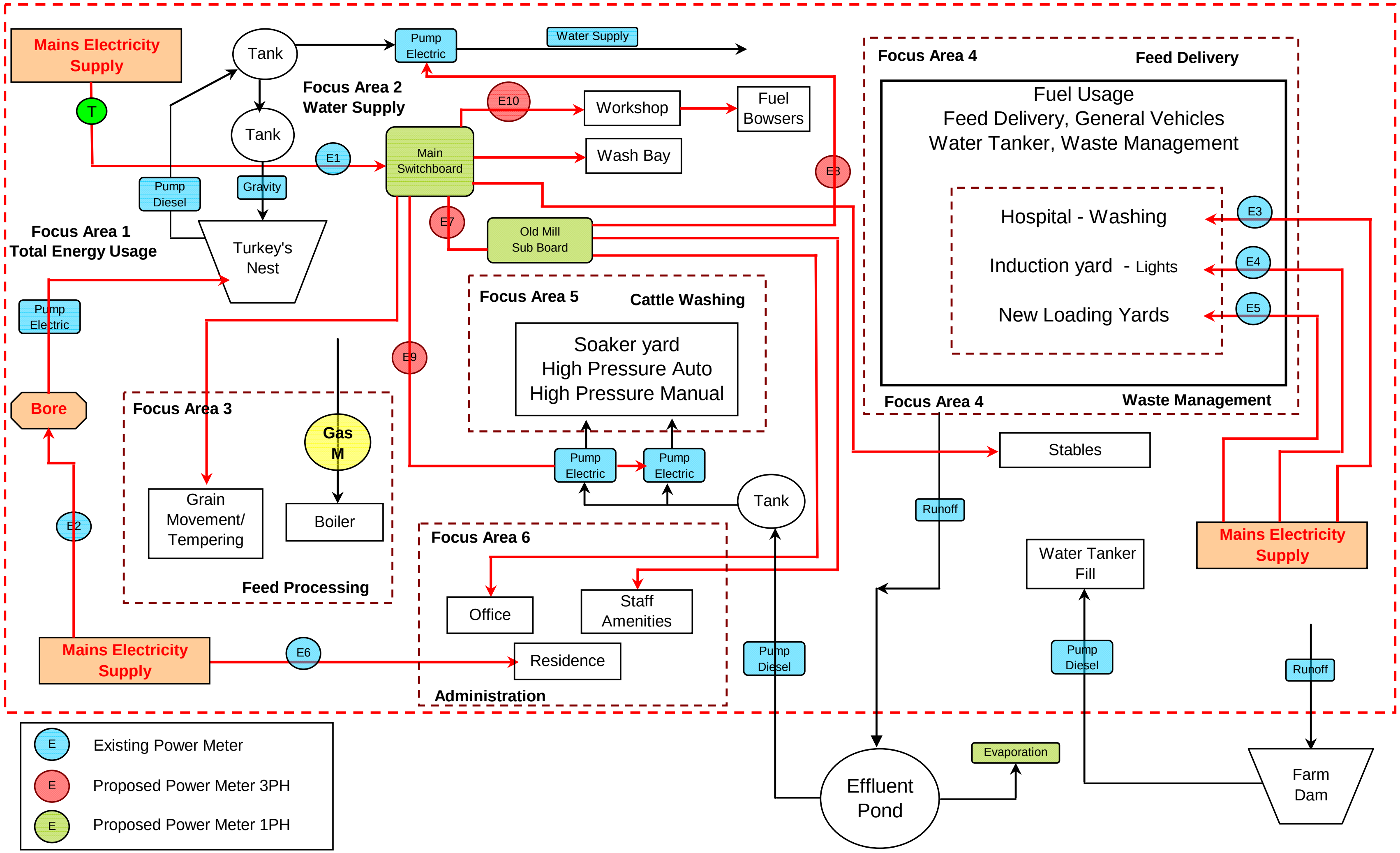



**Figure 11 - Energy supply network – Feedlot G**

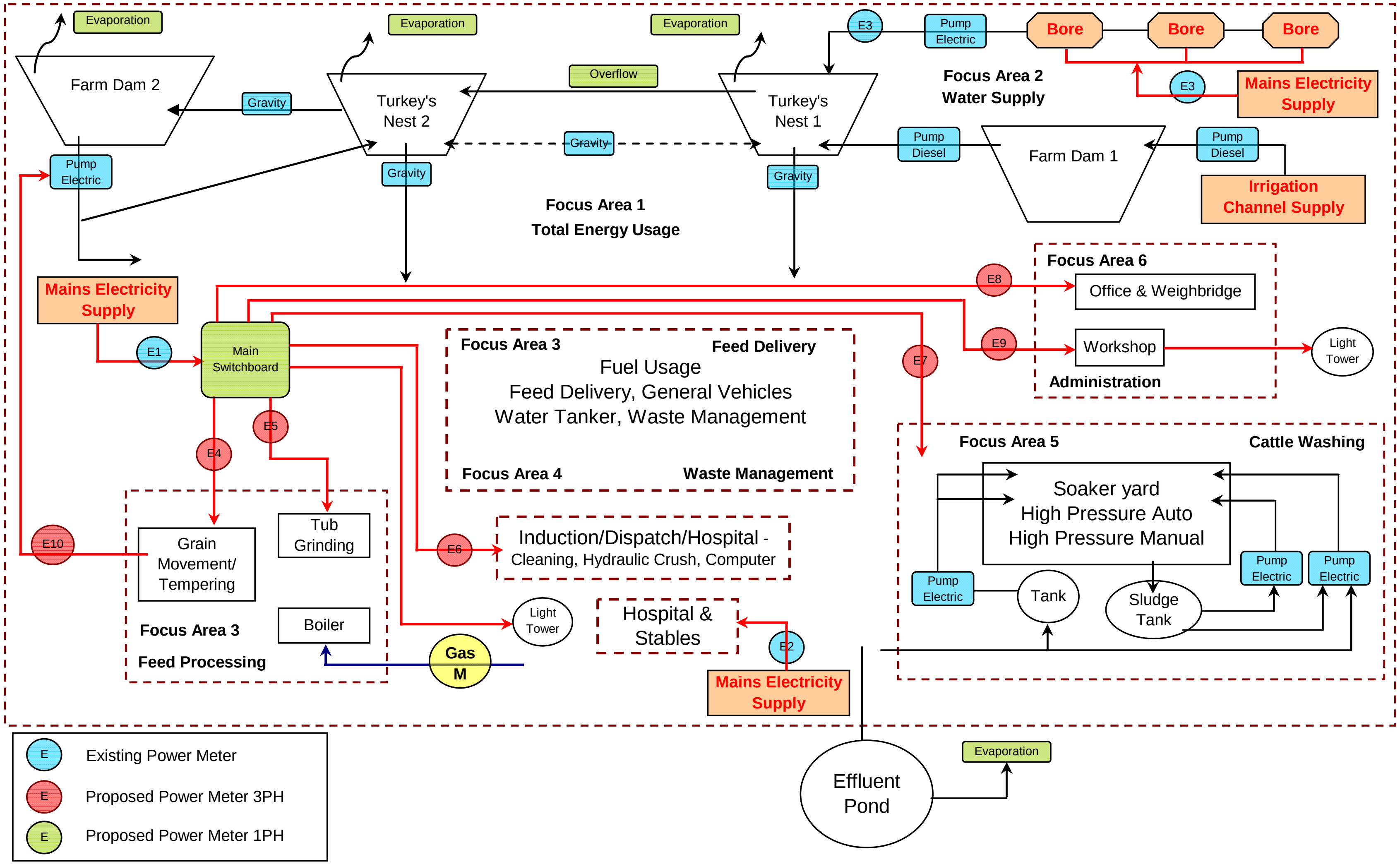



**Figure 12 - Energy supply network – Feedlot H**

## 4.5 Monthly direct and indirect energy usage recording

Each feedlot was given a recording sheet that detailed all energy metering onsite. This included power authority electricity metering, new power metering, gas metering and fuel metering.

No onsite metering had any digital recording capability. Hence, each meter had to be read manually at the end of each period. The nominal period was monthly. However, if the last day of the month fell on a weekend, the meters were read either prior too or soon after the last day of the month. Therefore, the nominal period varied from a minimum of 27 to a maximum of 33 days.

The power authority meters and newly installed power meters had a number allocated. The feedlot manager or a nominated staff member read the power authority and new power meters and recorded the reading on the recording sheet. The power authority metering allowed each phase power usage, high or off-peak supply usage or the total usage to be recorded. The new power meters provided only a total power usage. The reading along with the respective units in kilowatt hours (kWh) were recorded on the recording sheet.

At the same time, the gas reading in litres was recorded on the sheet. Fuel consumption was broken up into diesel and petrol usage. This information was obtained from fuel logbooks and grouped by the respective categories and recorded. The recording sheet was then faxed or emailed to FSA Consulting at the end of each month.

Indirect energy usage was estimated from cattle and commodity transport distances, and typical truck types. Information on transport distances and typical truck types was obtained directly from the respective feedlots in-house feedlot management software (e.g. FY3000). This information was recorded on the recording sheet and then faxed or emailed to FSA Consulting at the end of each month.

## 4.6 Monthly herd performance and feed consumption recording

Due to the potentially sensitive nature of the information produced by this research, the reported information is presented in such a way that individual feedlots cannot be identified. Therefore, energy use is presented as a function of a number of feedlot indices to protect the anonymity of the feedlot. The feedlot indices corresponded to the activity measured and included usage on a per head basis, per tonne grain processed and per kilogram of hot standard carcase weight gain (kg HSCW gain). In this context, HSCW gain is the difference between total dressed carcase weight of cattle leaving the feedlot less the estimated total dressed carcase weight of cattle entering the feedlot.

To enable the respective indices to be estimated, herd performance and feed consumption data was provided. Herd performance data was provided on a market type basis and included liveweight of incoming and shipped cattle, days on feed, average daily gain, dressing percentage, number of cattle entering the feedlot along with number shipped. Commodity usage for the period was provided, broken into categories of major grains, protein sources, roughages/silages, liquids and supplements.

The herd performance and feed consumption data was obtained directly from the respective feedlots in-house feedlot management software (e.g. Bunk Management System, Possum Gully, Feedlot

3000). These systems are dedicated cattle feeding software systems to assist operations in better managing assets, inventories, commodities and maintenance of financial records.

## 4.7 Data collection period

Monthly data was collected over a 12-month period from March 2007 to February 2008. This period allowed for the annual variation in total energy usage to be quantified along with the variation in individual feedlot activities.

## 4.8 Data analysis

Monthly power meter readings, fuel and gas usage figures were imported into a large Excel spreadsheet and cross-checked with previous month's readings. Where anomalous data were detected, the participating feedlot was contacted and the data were examined in more detail. Anomalous data may have included a reduction in meter reading from previous or unexplained extraordinarily large increases in power, fuel or gas usage.

Herd performance and feed consumption data were imported into the same spreadsheet. Similarly, data quality checks were undertaken. For example, the mean number of cattle on hand were compared with licensed capacity to ensure market types were not counted twice or missed. Where anomalous data was detected, the participating feedlot was contacted and the data were examined in more detail. The HSCW gain was calculated from the data for estimated liveweight in lot at the start of the month, total liveweight in, total liveweight out and estimated liveweight in lot at the end of the month. In some cases, feedlots were able to directly supply kilograms of beef produced for the month calculated from the identical method.

The spreadsheet then calculated the energy usage of the major feedlot activities as a function of their respective indices including on a per head basis, per tonne grain processed and per kilogram of hot standard carcase weight gain (kg HSCW gain).

# 5 Results and Discussion

Total indirect and direct energy usage and activity energy usage are presented in the following sections. It is important to note that the feedlot numbering system in the methodology section does not align with the number system in the results and discussion sections. That is, Feedlot B in Section 5.1 is not Feedlot B in Section 4.2. This has been deliberate to maintain anonymity for the participating feedlots.

TABLE 4 gives the conversion factors used to convert fuel usage to energy (MJ).

**Table 3 – Energy conversion factors for common fuels**

| Energy Form | **Units of Measure** | **Energy Conversion Factor MJ** |
|---|---|---|
| Diesel | Litres | 38.6 |
| Petrol | Litres | 34.2 |
| LPG | Litres | 25.7 |
| Natural | $m^3$ | 38.5 |
| Butane | Litres | 28.1 |
| Butane | $m^3$ | 122.0 |
| Electricity | kWh | 3.6 |

## 5.1 Total indirect energy usage

The energy (fuel consumed) for transport of incoming and outgoing livestock was calculated from cattle numbers, intake and exit liveweight, truck transport type (fuel usage & loading capacity) and estimated mean distance travelled to and from the feedlot. These data were supplied directly by the participating feedlots. Truck fuel usage and loading capacity was calculated from best available data. The raw consumption data for the respective fuel type was then converted into an equivalent energy consumption and then standardised per kg HSCW gain.

Truck transport fuel usage was determined from gathering transport industry data on average fuel use per 100 km for different truck types. TABLE 4 shows the average fuel use per 100 km for different truck types commonly used for livestock transport. Fuel consumption is a function of the efficiency of vehicle weight, fuel technology, topography, road conditions as well as other factors. The fuel usage presented here is only an average based typical highway performance for fully loaded vehicles.

**Table 4 – Fuel usage for livestock and commodity transport vehicles**

| | Table Top | Semi Trailer | Semi Trailer | B Double | Road Train |
|---|---|---|---|---|---|
| | 1 Deck | 1 Deck | 2 Deck | 3 Decks | 4 Decks |
| Fuel (L) / 100 km | 23.8 | 34.55 | 42.6 | 56.8 | 68.4 |

Loading capacity depends upon truck type and size of the livestock. Loading rates were taken from Davies, Blackwood and Richards (2002).

TABLE 5 shows average livestock loading rates for different truck types commonly used for livestock transport.

From TABLE 5, and the number of incoming and outgoing cattle, it was possible to calculate the number of incoming and outgoing vehicles. When multiplied by the estimated travel distance, the total kilometres of livestock transport was calculated. From TABLE 4, it was possible to estimate fuel use.

**Table 5 – Livestock loading rates (head per vehicle) for livestock transport truck types**

| Animal LWT | Table Top | Semi Trailer | Semi Trailer | B double | Road Train |
|---|---|---|---|---|---|
| kg | 1 deck | 1 deck | 2 decks | 3 decks | 4 decks |
| 250 | 22 | 38 | 75 | 114 | 150 |
| 300 | 20 | 34 | 67 | 102 | 134 |
| 350 | 18 | 30 | 60 | 91 | 120 |
| 400 | 16 | 28 | 55 | 83 | 110 |
| 450 | 15 | 25 | 51 | 77 | 102 |
| 500 | 14 | 24 | 47 | 71 | 94 |
| 550 | 13 | 22 | 43 | 65 | 86 |
| 600 | 12 | 20 | 39 | 59 | 78 |
| 650 | 11 | 18 | 35 | 54 | 70 |
| 700 | 10 | 16 | 32 | 49 | 64 |
| 750 | 9 | 14 | 28 | 44 | 56 |
| 800 | 8 | 12 | 24 | 39 | 48 |

Similarly, the energy (fuel consumed) for transport of off-farm feed commodities to the feedlot was calculated from the mass of each commodity delivered, type of truck delivering commodity (fuel usage & loading capacity) and estimated mean delivery distance. These data were provided by the participating feedlot. Truck fuel usage and loading capacity was calculated from best available data. The energy used to transport commodities produced on-farm to the feedlot were not included in these figures.

TABLE 4 shows the average fuel use per 100 km for different truck types commonly used for commodity transport.

Loading capacity depends upon truck type and the density of the commodity delivered. The loading capacity was determined from gathering transport industry data on average commodity loading rates for different truck types. TABLE 6 shows average loading capacity for different truck types commonly used for commodity transport.

**Table 6 – Loading rates for commodity delivery vehicles**

| Commodity | Body Truck, 10t | Truck and Dog | Semi Trailer | B Double | Road Train |
|---|---|---|---|---|---|
| | tonnes | tonnes | tonnes | tonnes | tonnes |
| Roughages/Straws | 6 | 12 | 12 | 18 | 24 |
| Fully prepared ration | 12 | 24 | 24 | 36 | 48 |
| Liquids | 12 | 24 | 24 | 36 | 48 |
| Major Grains | 12 | 24 | 24 | 36 | 48 |
| Molasses | 12 | 24 | 24 | 36 | 48 |
| Protein Sources | 12 | 24.5 | 25.5 | 37 | 50 |
| Silage | 12 | 25 | 25 | 36 | 50 |

FIGURE 13 to FIGURE 19 inclusive present the monthly results for the period March 2007 to February 2008 of the energy use for livestock transport and commodity delivery for the seven feedlots. The usage for the respective activities was standardised per kg HSCW gain for the respective month. These figures clearly show the impact of travel distance on energy consumption for livestock transport and commodity delivery.

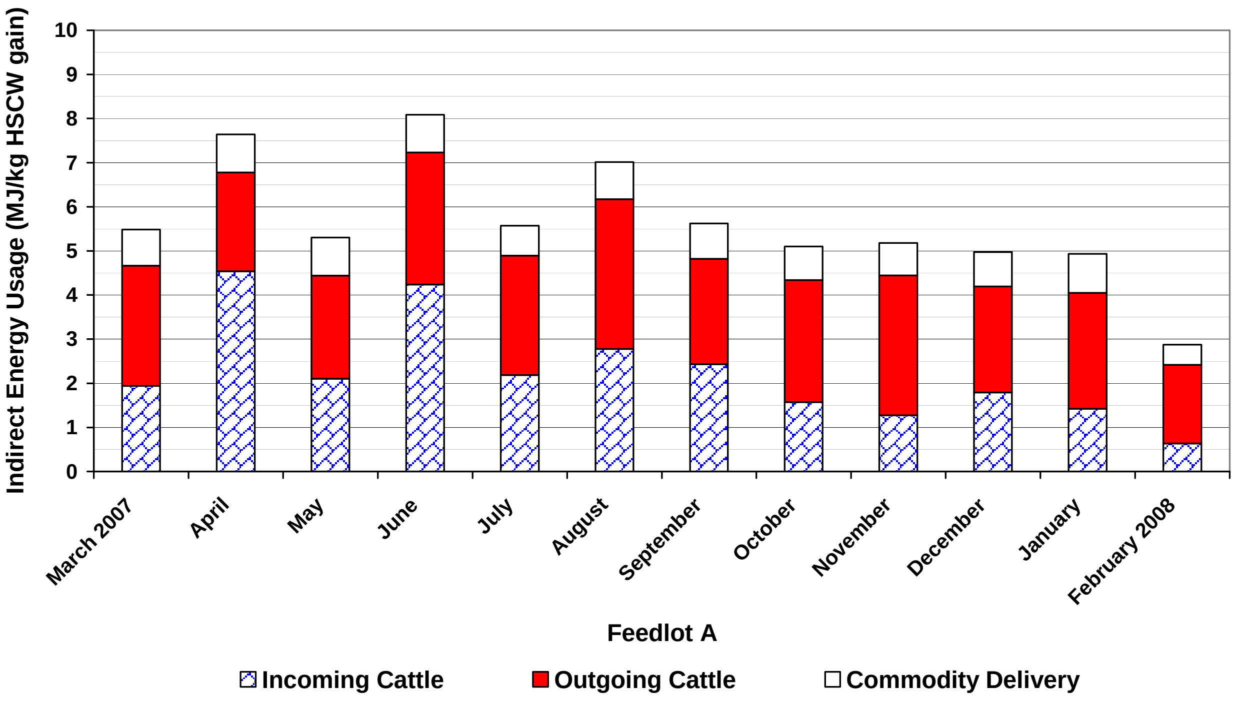



**Figure 13 – Monthly total indirect energy usage at Feedlot A (MJ/kg HSCW gain)**

Figure 13 shows the total indirect energy usage for Feedlot A during the period March 2007 to March 2008. For Feedlot A, the total indirect energy usage ranges from 2.9 MJ/kg HSCW gain in February 2008 to 8 MJ/kg HSCW gain in June 2007. The primary driver of total energy usage is incoming cattle with a fourfold variation in energy usage. Outgoing cattle and commodity delivery are similar between months.

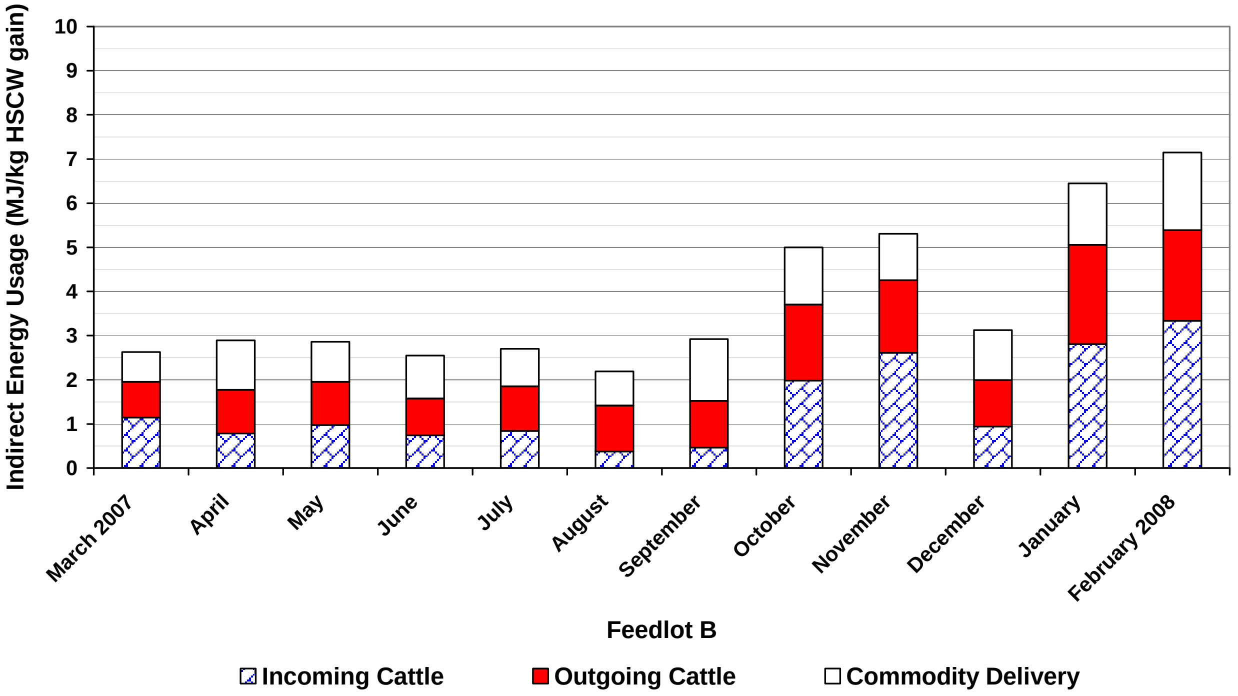



**Figure 14 – Monthly total indirect energy usage at Feedlot B (MJ/kg HSCW gain)**

FIGURE 14 shows the total indirect energy usage for Feedlot B during the period March 2007 to March 2008. For Feedlot B, the total indirect energy usage ranges from 2.1 MJ/kg HSCW gain in August 2007 to 7.2 MJ/kg HSCW gain in February 2008. Energy consumed in transport of cattle to slaughter ranges from 0.81 MJ/kg HSCW gain to 2.2 MJ/kg HSCW gain. Between March and September 2007, the total energy usage was relatively similar and less than 3 MJ/kg HSCW gain. From October 2007 to February 2008, energy usage has risen steadily across all activities to a peak of 7.2 MJ/kg HSCW gain.

FIGURE 15 shows the total indirect energy usage for Feedlot C during the period March 2007 to March 2008. For Feedlot C, the total indirect energy usage ranges from 1.6 MJ/kg HSCW gain to 3.5 MJ/kg HSCW gain. Feedlot C and Feedlot G have the lowest average total indirect energy usage across all feedlots. The largest component of total energy usage is commodity delivery, representing on average 53% of total energy usage. Outgoing cattle is similar between months, with a low figure recorded in September and October 2007.

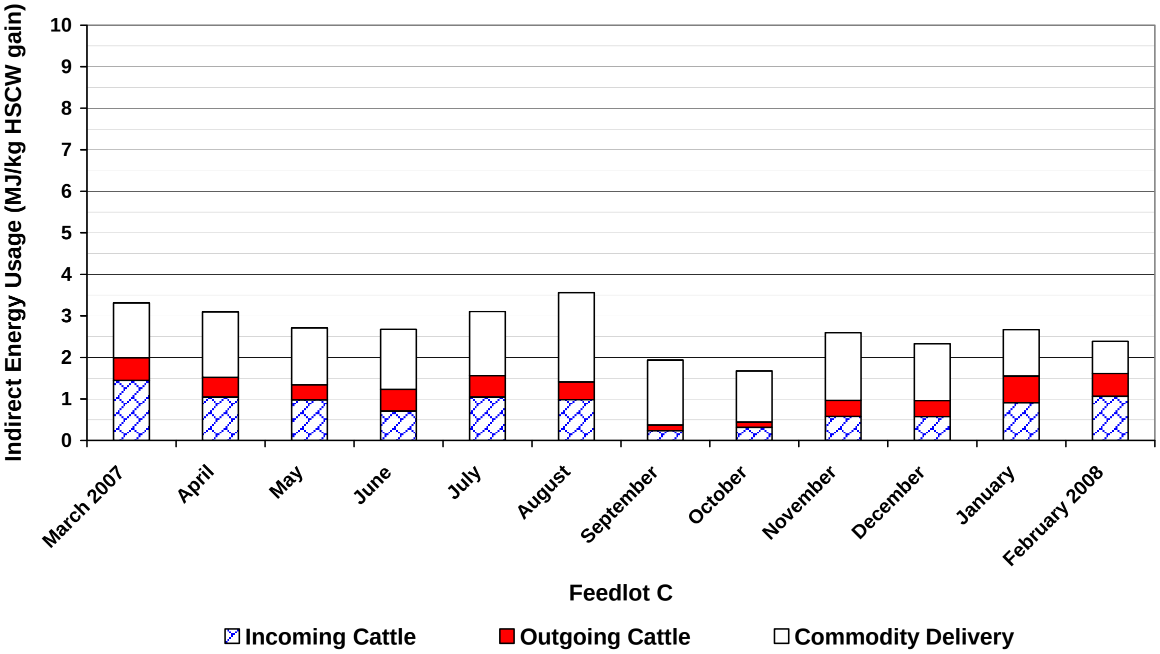



**Figure 15 – Monthly total indirect energy usage at Feedlot C (MJ/kg HSCW gain)**

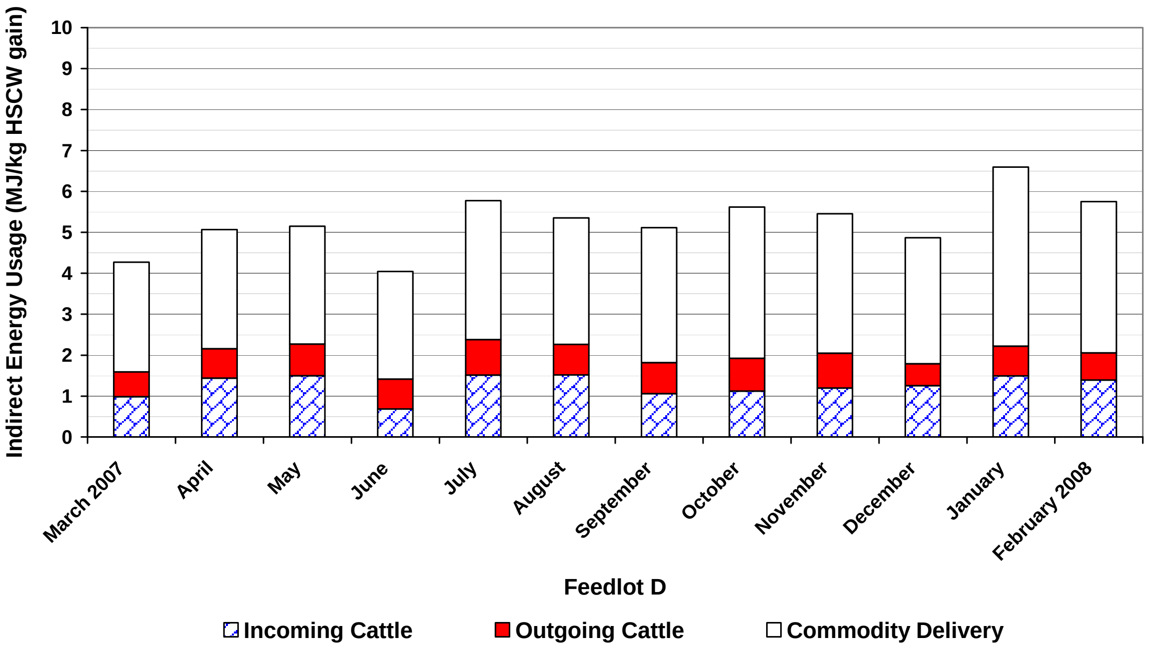



**Figure 16 – Monthly total indirect energy usage at Feedlot D (MJ/kg HSCW gain)**

Figure 16 shows the total indirect energy usage for Feedlot D during the period March 2007 to March 2008. For Feedlot D, the total indirect energy usage ranges from 4.0 MJ/kg HSCW gain in June 2007 to 6.6 MJ/kg HSCW gain in January 2008. The largest component of total energy usage is commodity delivery, representing on average 62% of total energy usage. Incoming and outgoing cattle are similar between months. Commodity delivery energy usage ranges from 2.6 MJ/kg HSCW gain to 4.4 MJ/kg HSCW gain. Outgoing cattle energy usage ranges from 0.5 MJ/kg HSCW gain to 0.9 MJ/kg HSCW gain.

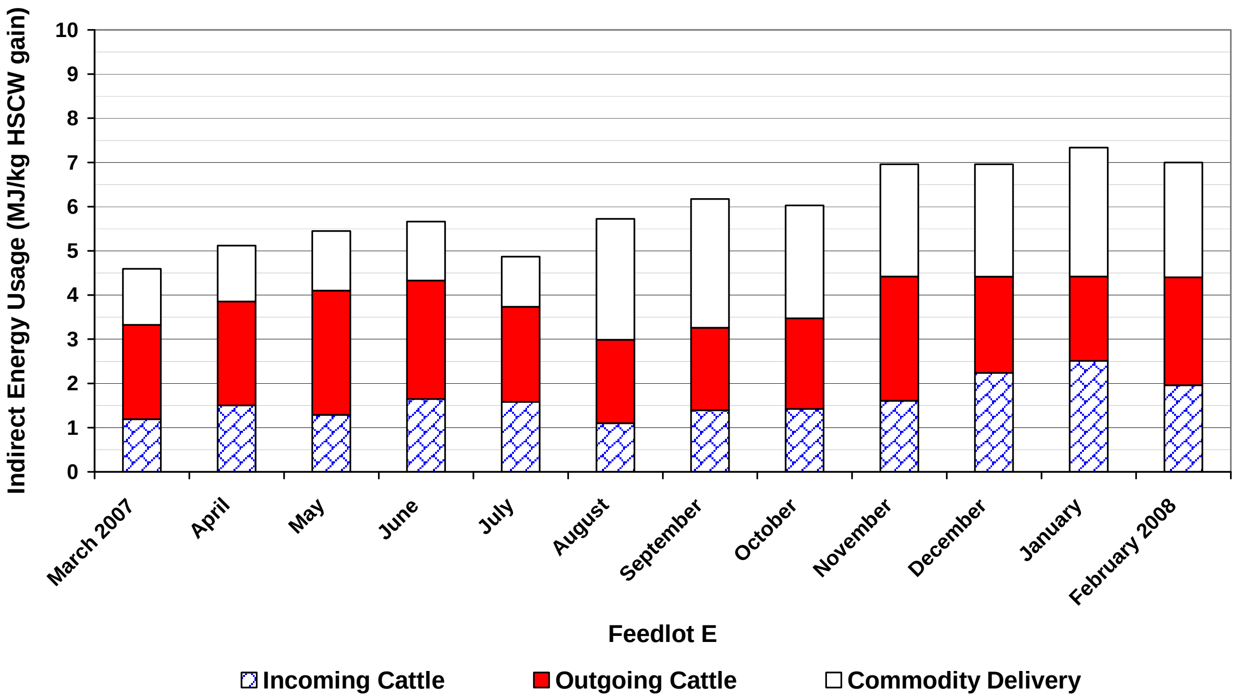



**Figure 17 – Monthly total indirect energy usage at Feedlot E (MJ/kg HSCW gain)**

FIGURE 17 shows the total indirect energy usage for Feedlot E during the period March 2007 to March 2008. For Feedlot E, the total indirect energy usage ranges from 4.6 MJ/kg HSCW gain in July 2007 to 7.4 MJ/kg HSCW gain in January 2008. For this feedlot, incoming cattle represents the lowest energy usage in the order of 27%, whilst outgoing cattle (38%) and commodity delivery (35%) contributed the remaining energy usage. Commodity delivery energy usage ranges from 1.1 MJ/kg HSCW gain to 2.9 MJ/kg HSCW gain. Outgoing cattle energy usage ranges from 1.9 MJ/kg HSCW gain to 2.8 MJ/kg HSCW gain.

Figure 18 shows the total indirect energy usage for Feedlot F during the period March 2007 to March 2008. For Feedlot F, the total indirect energy usage ranges from 3.5 MJ/kg HSCW gain in September 2007 to 7.9 MJ/kg HSCW gain in November 2007. For this feedlot, transport of cattle to slaughter represents the lowest energy usage in the order of 13%, whilst incoming cattle (27%) and commodity delivery (60%) contributed the remaining energy usage. Commodity delivery energy usage ranges from 2.2 MJ/kg HSCW gain to 5.2 MJ/kg HSCW gain. Outgoing cattle energy usage ranges from 0.5 MJ/kg HSCW gain to 0.9 MJ/kg HSCW gain, whilst incoming cattle energy usage ranges from 0.3 MJ/kg HSCW gain to 4.3 MJ/kg HSCW gain.

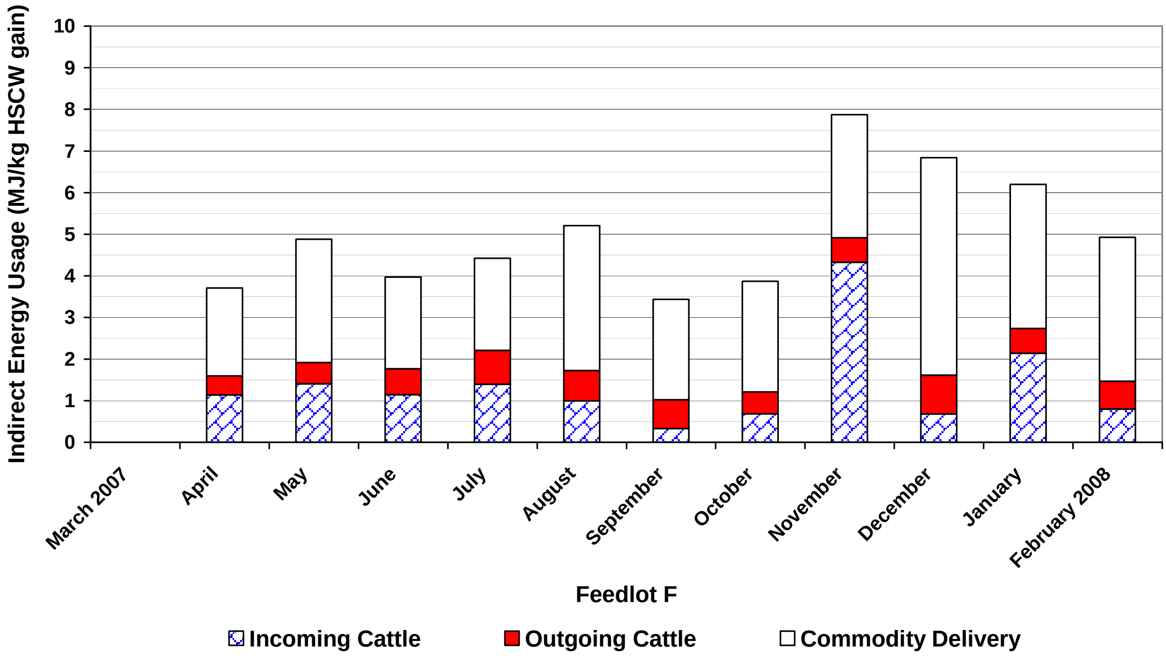



**Figure 18 – Monthly total indirect energy usage at Feedlot F (MJ/kg HSCW gain)**

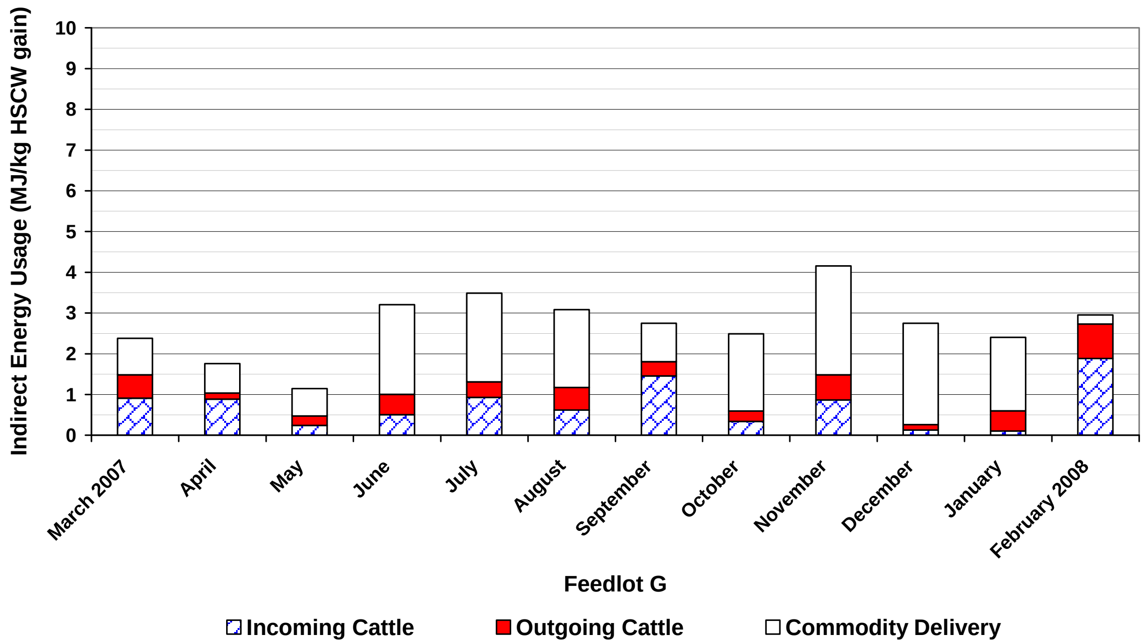



**Figure 19 – Monthly total indirect energy usage at Feedlot G (MJ/kg HSCW gain)**

FIGURE 19 shows the total indirect energy usage for Feedlot G during the period March 2007 to March 2008. For Feedlot G, the total indirect energy usage ranges from 1.1 MJ/kg HSCW gain in May 2007 to 4.2 MJ/kg HSCW gain in November 2007. Feedlot G and Feedlot C have the lowest average total indirect energy usage across all feedlots. For this feedlot, transport of cattle to slaughter represents the lowest energy usage in the order of 15%, whilst incoming cattle (27%) and commodity delivery (58%) contributed the remaining energy usage. Commodity delivery energy usage ranges from 0.7 MJ/kg HSCW gain to 2.6 MJ/kg HSCW gain. Outgoing cattle energy usage ranges from 0.15 MJ/kg HSCW gain to 0.84 MJ/kg HSCW gain, whilst incoming cattle energy usage ranges from 0.24 MJ/kg HSCW gain to 1.9 MJ/kg HSCW gain.

The indirect energy usage figures illustrate the proximity of respective feedlots to cattle, abattoirs and commodities. These figures also are influenced by the differences in average daily gain between long fed cattle and domestic cattle, number and type of commodities used in rations (high grain versus high roughage). These results also clearly show the effect of the drought (grain and available cattle supply) and high grain prices on the industry in particular during the latter half of 2007 and early 2008, where higher energy usage figures were recorded. Feedlot G is a smaller feedlot and therefore is able to source cattle and feed locally. This is reflected in lower indirect energy costs.

## 5.2 Total direct energy usage

FIGURE 20 to FIGURE 32 inclusive present the monthly total direct energy use for the seven feedlots from March 2007 to February 2008. Total energy usage is the combination of water supply, feed management (processing and delivery), cattle washing (where this practice is undertaken), administration and minor activities uses such as repairs and maintenance and cattle management. The usage for the respective activities was standardised per kg HSCW gain and per head on feed for the respective month.

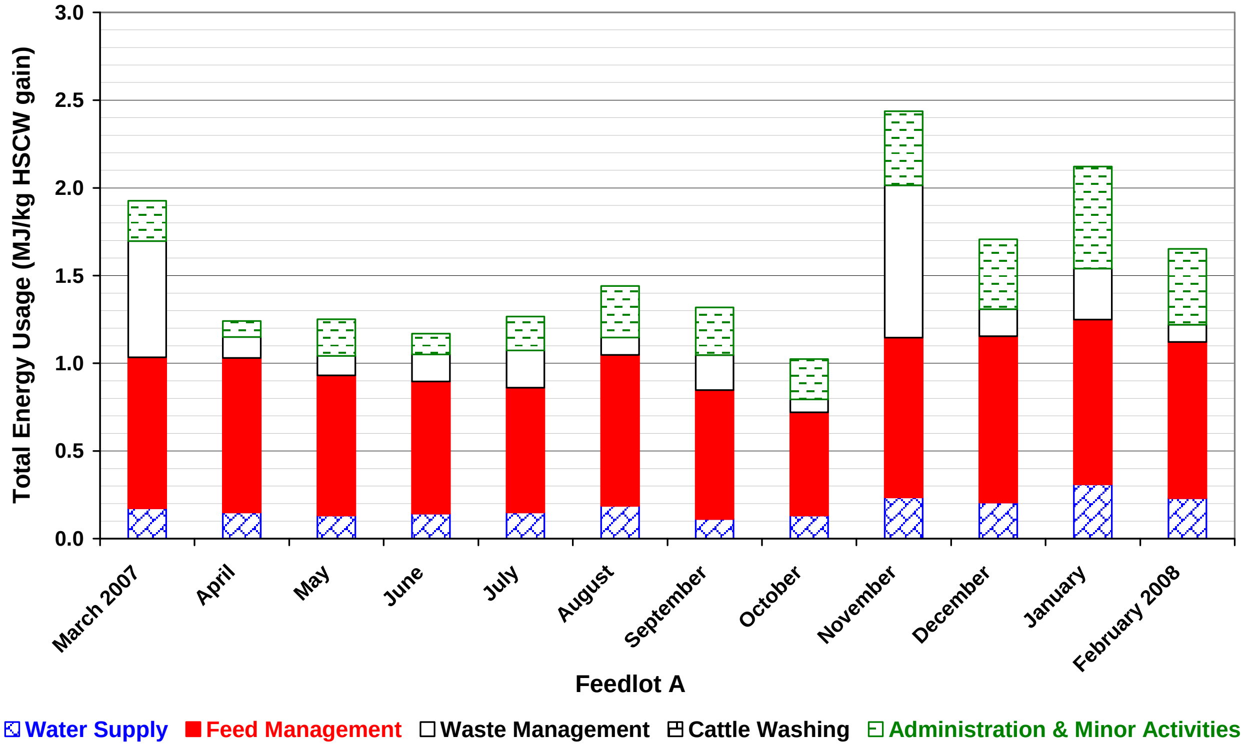



**Figure 20 – Monthly total energy usage at Feedlot A (MJ/kg HSCW gain)**

FIGURE 20 shows the total monthly energy usage at Feedlot A for the period March 2007 to February 2008. At Feedlot A, the total monthly energy use ranges from 1.0 to 2.4MJ/kg HSCW gain. The lowest energy usage was measured in spring (October) and the highest in the following month, November. In months where pen cleaning only is undertaken, feed management is the single largest consumer of energy in the feedlot as expected and contributed 0.6 to 0.95 MJ/kg HSCW gain or in the order of 50 % of total usage. In March and November waste management energy usage contributed 0.66 MJ/kg HSCW gain (38 %) and 0.87 MJ/kg HSCW gain (39 %) of total energy usage respectively. Typically, waste management contributes 18 % of total energy usage. Water supply contributed an average of 0.18 L/kg HSCW gain or around 12 % of total usage. No cattle were washed during the study period at this feedlot. Administration and minor activities (20 %) contribute the remaining usage. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

FIGURE 21 shows the total monthly energy usage at Feedlot A on a MJ/head on feed basis for the period March 2007 to February 2008.

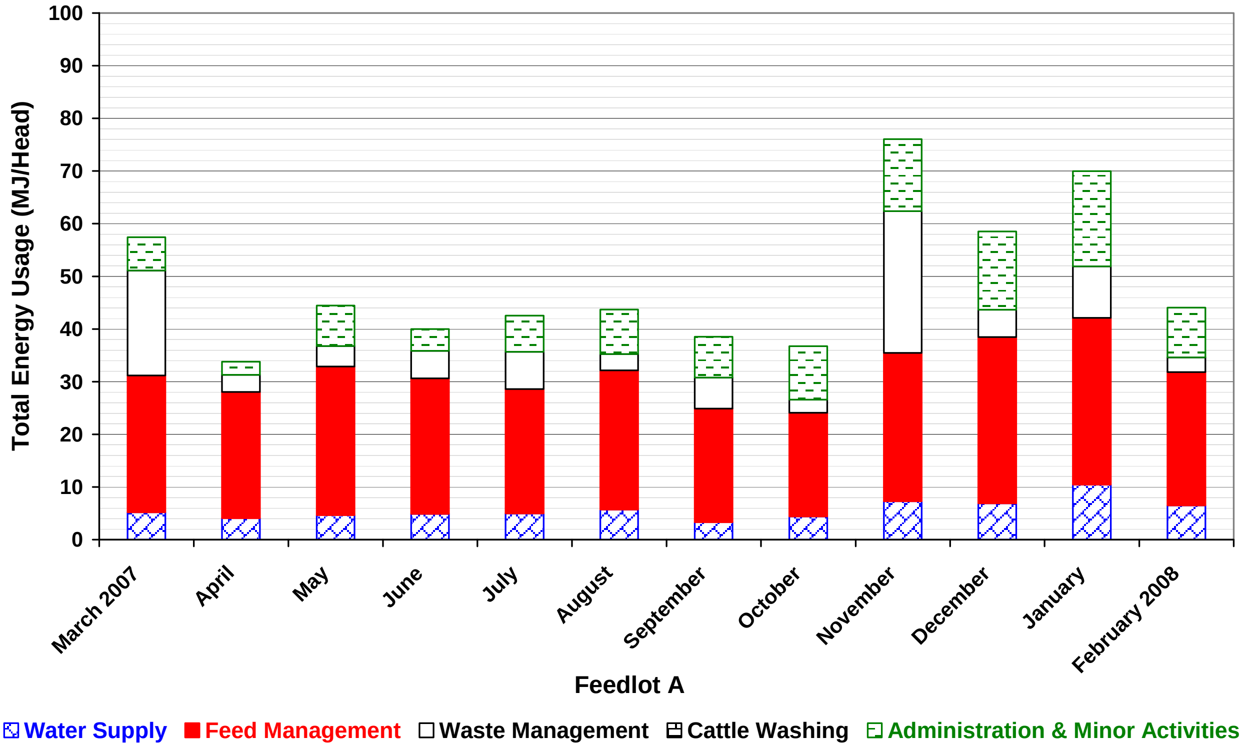



**Figure 21 – Monthly total energy usage at Feedlot A (MJ/head on feed/month)**

At Feedlot A, the total monthly energy use ranges from 32 to 76 MJ/head on feed/month. The total energy usage for the year is 585 MJ/head on feed. This compares with the lower end of the range of 450 – 1300 MJ/head on feed/yr found by Davis and Watts (2006). In months where pen cleaning only is undertaken, feed management is the single largest consumer of energy in the feedlot. The effect of lower head on feed from November is evident with higher energy consumption per head when compared to previous months. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

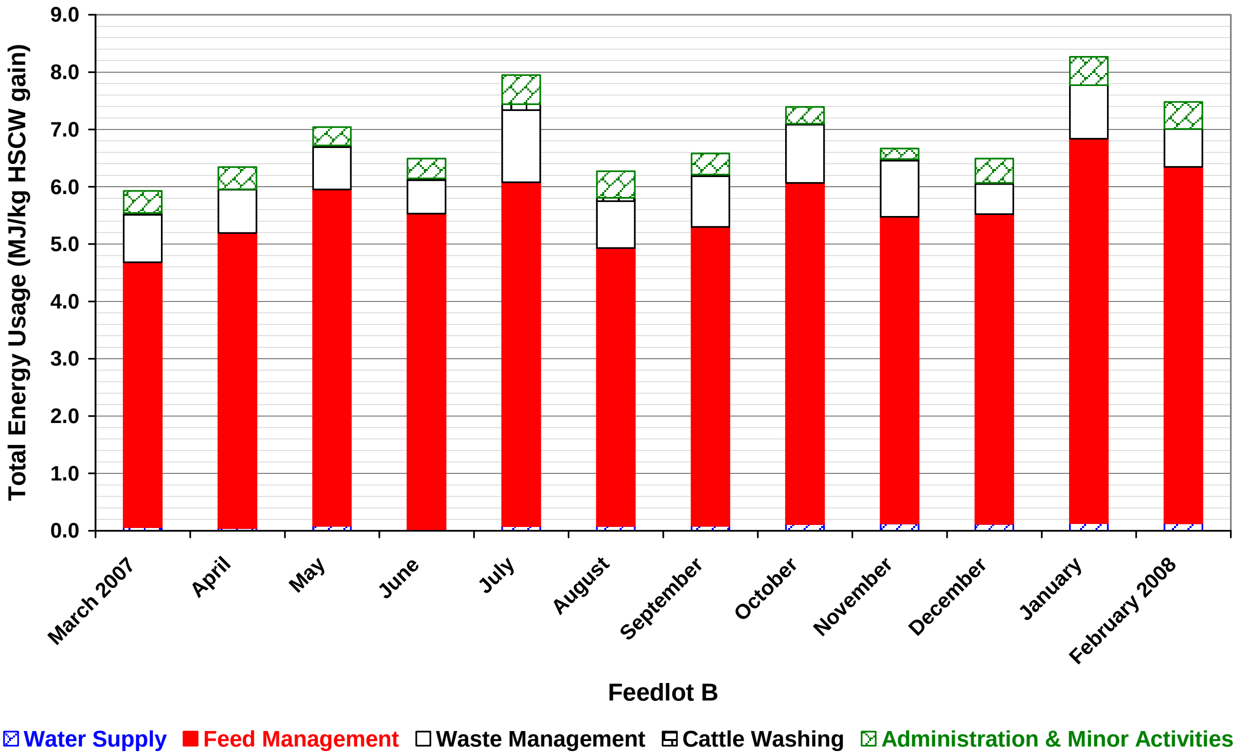



**Figure 22 – Monthly total energy usage at Feedlot B (MJ/kg HSCW gain)**

FIGURE 22 shows the total monthly energy usage at Feedlot B for the period March 2007 to February 2008. At Feedlot B, the total monthly energy use ranges from 6.0 to 8.3 MJ/kg HSCW gain. The lowest energy usage was measured in March and the highest in January 2008. Feed management is the single largest consumer of energy in the feedlot as expected and contributed 4.85 to 6.7 MJ/kg HSCW gain or in the order of 80 % of total usage. Waste management energy usage contributed between 0.59 MJ/kg HSCW gain (9 %) and 1.26 MJ/kg HSCW gain (16 %) of total energy usage. On average, waste management is 12% of the total energy usage. Water supply contributed an average of 0.09 L/kg HSCW gain or around 2 % of total usage. Cattle washing contributed between 0.02 MJ/kg HSCW gain (0.3 %) and 0.1 MJ/kg HSCW gain (1 %) of total energy usage. The energy consumed in cattle washing is directly related to the volume of water used. Administration and minor activities (5 %) contribute the remaining usage. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

FIGURE 23 shows the total monthly energy usage at Feedlot B on a MJ/head on feed basis for the period March 2007 to February 2008.

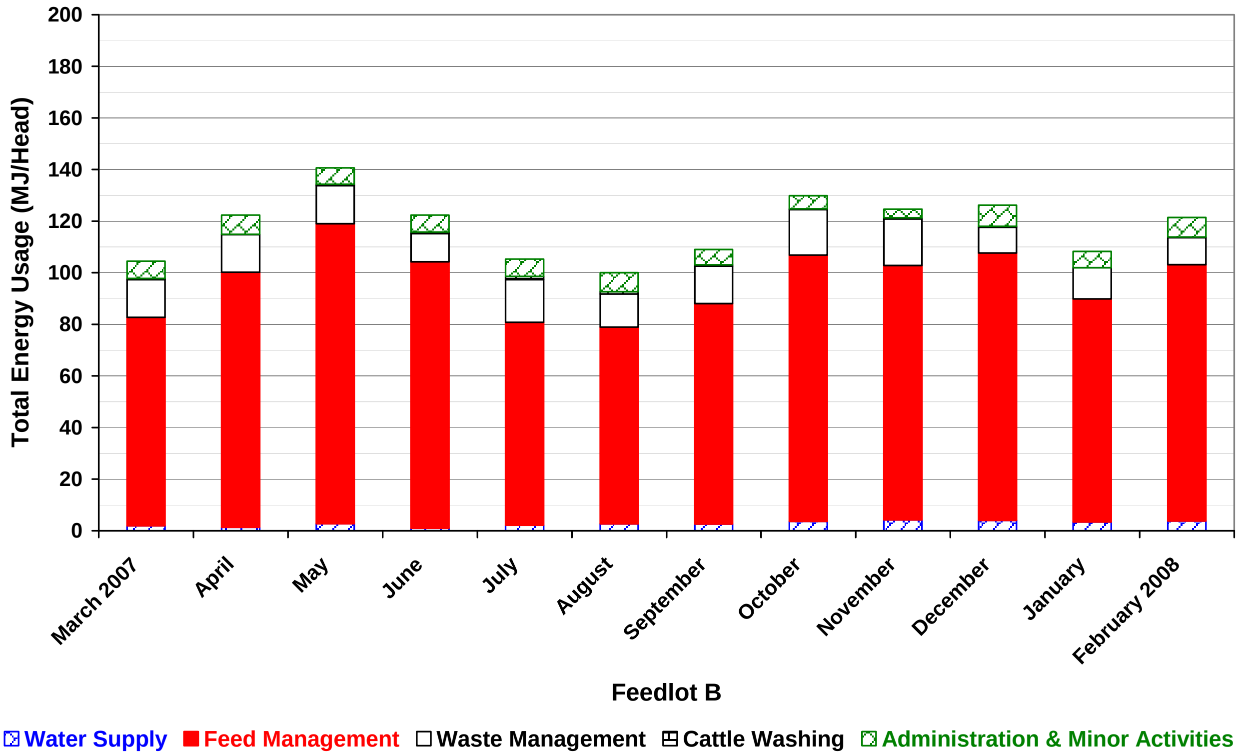



**Figure 23 – Monthly total energy usage at Feedlot B (MJ/head on feed/month)**

At Feedlot B, the total monthly energy use ranges from 100 to 141 MJ/head on feed/month. The total energy usage for the year is 1415 MJ/head on feed. This is a higher figure than the 1300 MJ/head on feed maximum recorded by Davis and Watts (2006). Feed management is the single largest consumer of energy in the feedlot. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

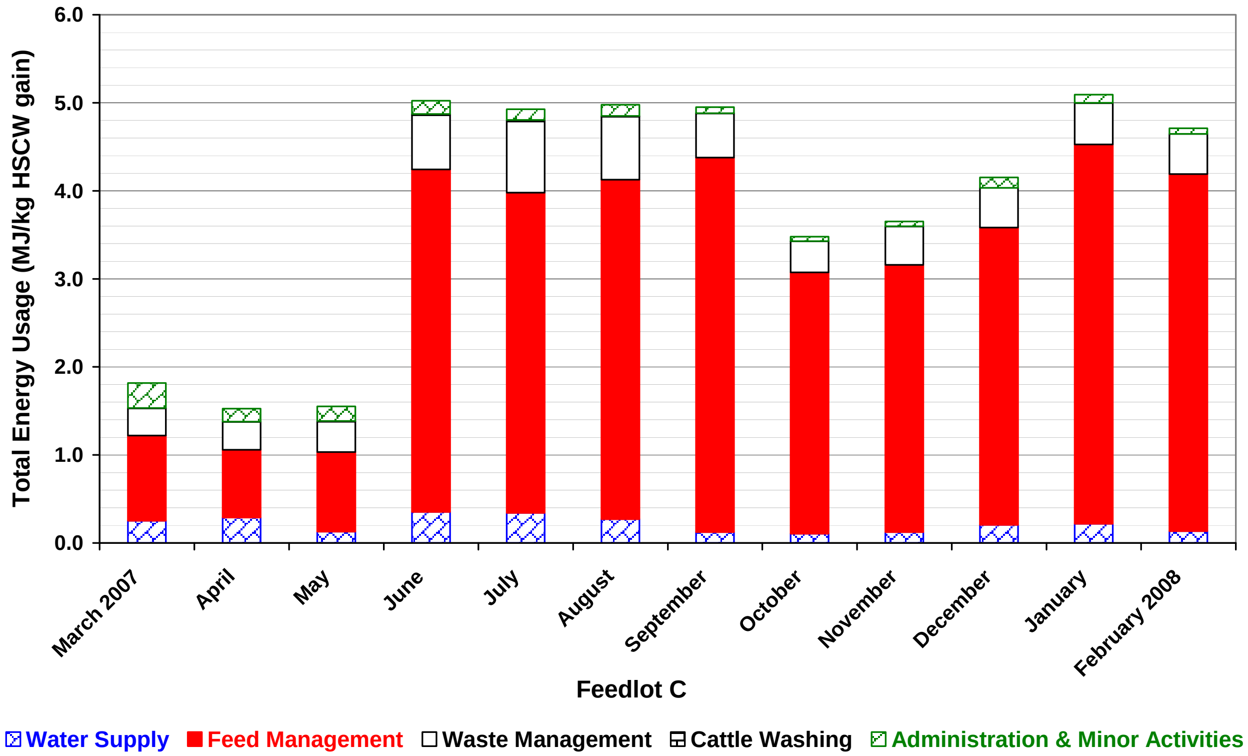



**Figure 24 – Monthly total energy usage at Feedlot C (MJ/kg HSCW gain)**

FIGURE 24 shows the total monthly energy usage at Feedlot C for the period March 2007 to February 2008. At Feedlot C, for months March to May the total monthly energy use ranged from 1.5 to 1.9 MJ/kg HSCW gain whilst for June to February, the total monthly energy use ranged from 3.4 to 5.1MJ/kg HSCW gain. Commissioning of a steam flaking feed processing system in June 2007, accounts for the increased total energy usage. Feed management is the largest single consumer of energy in the feedlot. For the period, March to May feed management contributed 0.8 to 1 MJ/kg HSCW gain or in the order of 42 % of total usage. For the period, June to July feed management contributed 2.9 to 4.3 MJ/kg HSCW gain or in the order of 80 % of total usage. Waste management energy usage contributed an average 0.32 MJ/kg HSCW gain (23 %) for March to May, whilst from June to February it averaged 0.53 MJ/kg HSCW gain or 12 % of total energy usage.

Water supply contributed an average of 0.21 MJ/kg HSCW gain or around 5 % of total usage with steam flaking and 16% with tempering only. Cattle washing contributed an average of 0.02 MJ/kg HSCW gain (<1 %) of total energy usage. The energy consumed in cattle washing is directly related to the volume of water used. Administration and minor activities (15 %) contribute the remaining usage during March to May and 2% for the period June to February. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

FIGURE 24 shows the total monthly energy usage at Feedlot B on a MJ/head on feed basis for the period March 2007 to February 2008.

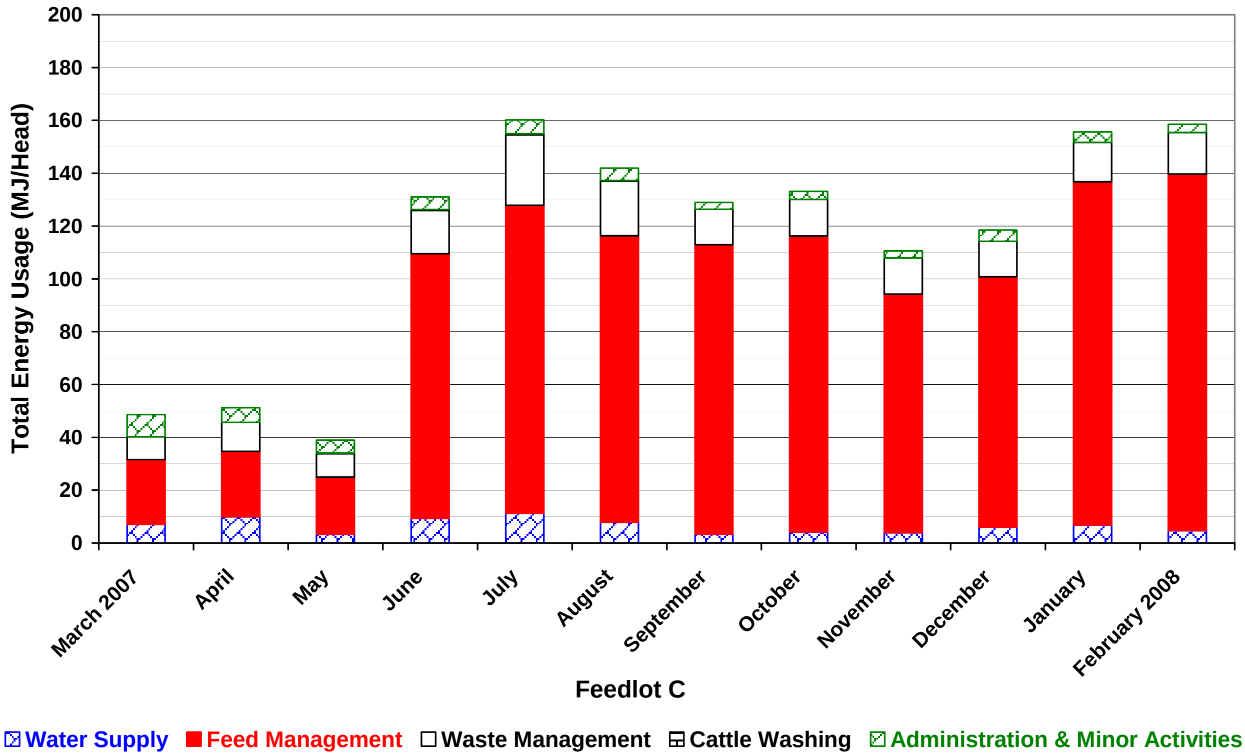



**Figure 25 – Monthly total energy usage at Feedlot C (MJ/head on feed/month)**

At Feedlot C, the total monthly energy use ranged from 40 to 51 MJ/head on feed/month when grain was tempered only. This increased to a minimum of 110 to a maximum of 160 MJ/head on feed when the steam flaking unit was in use. The total energy usage for the year is 1377 MJ/head on feed. Feed management is the single largest consumer of energy in the feedlot. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

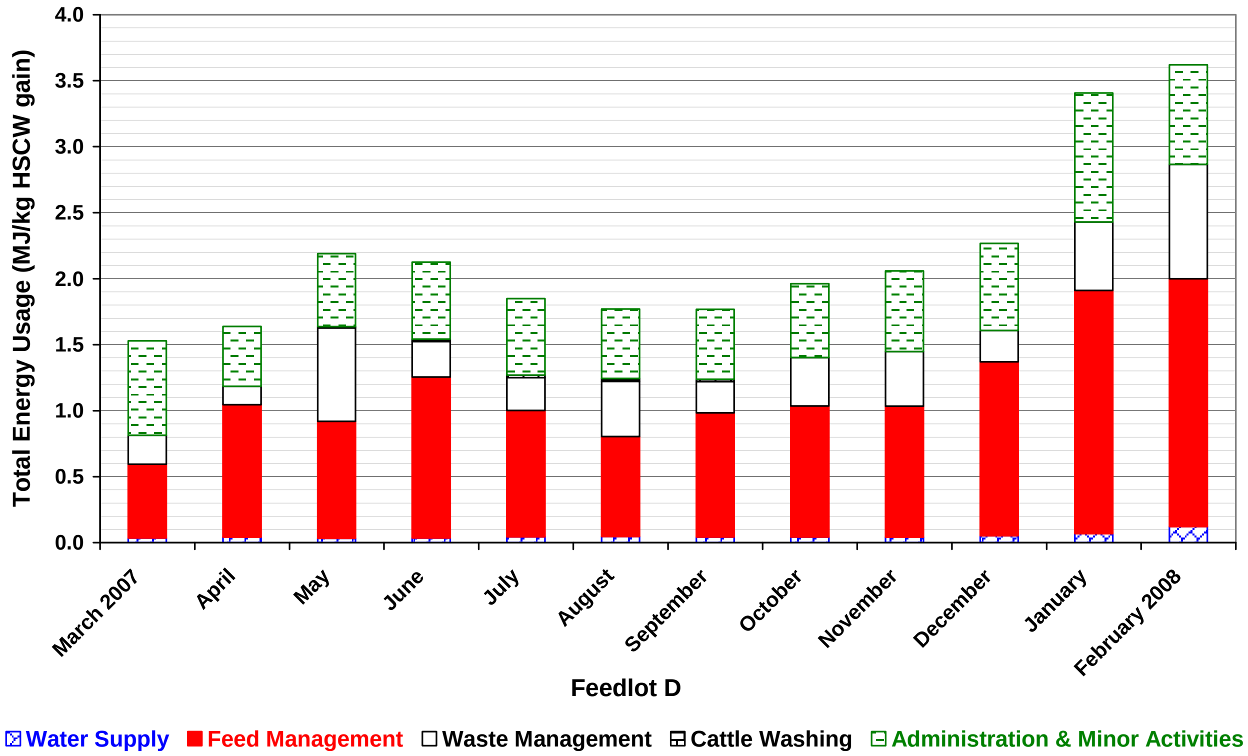



**Figure 26 – Monthly total energy usage at Feedlot D (MJ/kg HSCW gain)**

FIGURE 26 shows the total monthly energy usage at Feedlot D for the period March 2007 to February 2008. At Feedlot D, the total monthly energy use ranges from 1.5 to 2.6 MJ/kg HSCW gain. The lowest energy usage was measured in March and the highest in January 2008. Feed management is the single largest consumer of energy in the feedlot as expected and contributed 0.56 to 1.88 MJ/kg HSCW gain or in the order of 60 % of total usage. Waste management energy usage contributed between 0.14 MJ/kg HSCW gain (13 %) and 0.87 MJ/kg HSCW gain (31 %) of total energy usage. On average, waste management is 25% of the total energy usage. Water supply contributed an average of 0.05 MJ/kg HSCW gain or around 3 % of total usage. Cattle washing contributed an average of 0.02 MJ/kg HSCW gain (1.5 %) of total energy usage. The energy consumed in cattle washing is directly related to the volume of water used. Administration and minor activities contribute in the order of 10% of the total energy usage. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

FIGURE 27 shows the total monthly energy usage at Feedlot D on a MJ/head on feed/month basis for the period March 2007 to February 2008.

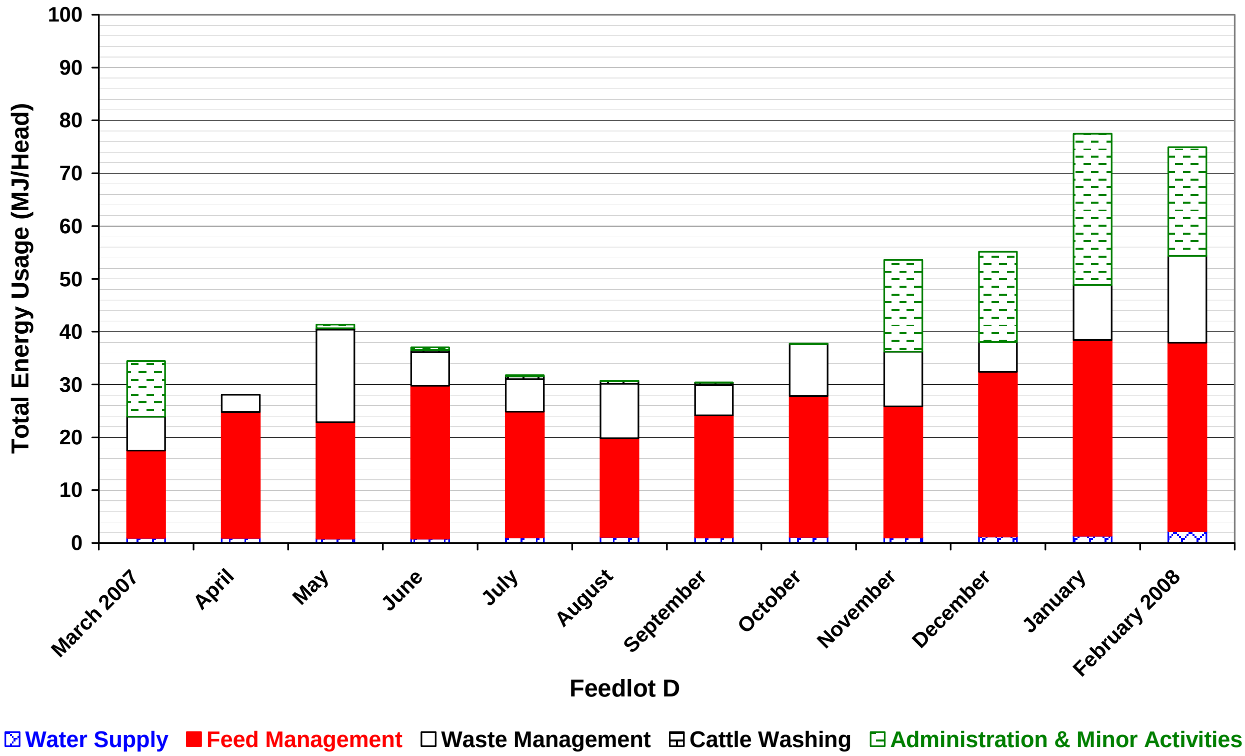



**Figure 27 – Monthly total energy usage at Feedlot D (MJ/head on feed/month)**

At Feedlot D, the total monthly energy use ranges from 28 to 78 MJ/head on feed/month. The total energy usage for the year is 532 MJ/head on feed. Feed management is the single largest consumer of energy in the feedlot followed by administration and minor activities (note this includes repairs and maintenance and residence). Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

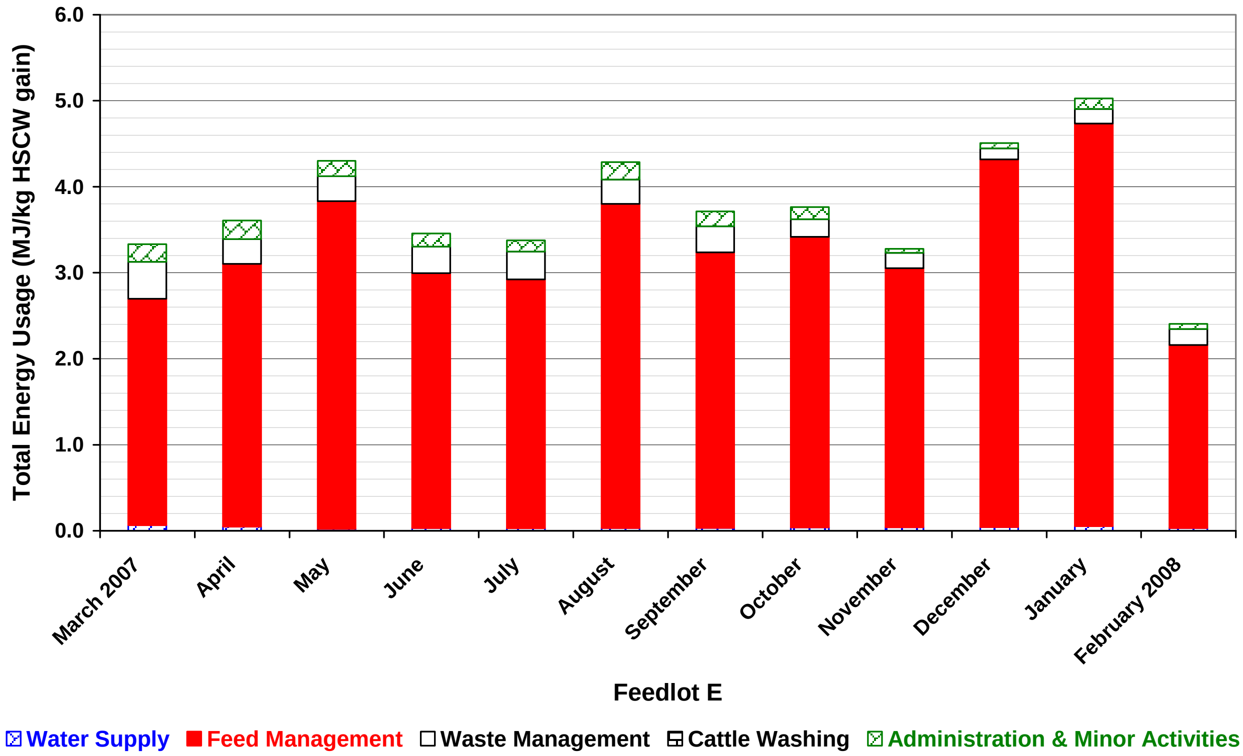



**Figure 28 – Monthly total energy usage at Feedlot E (MJ/kg HSCW gain)**

FIGURE 28 shows the total monthly energy usage at Feedlot E for the period March 2007 to February 2008. At Feedlot E, the total monthly energy use ranges from 2.4 (February 2008) to 5.0 MJ/kg HSCW gain (January 2008). Feed management is the largest single consumer of energy in the feedlot as expected and contributed 2.1 to 4.7 MJ/kg HSCW gain or in the order of 88 % of total usage. Waste management energy usage contributed between 0.13 MJ/kg HSCW gain (3 %) and 0.43 MJ/kg HSCW gain (13 %) of total energy usage, however on average represents 7% of the total energy usage. Water supply contributed an average of 0.04 MJ/kg HSCW gain or around 1 % of total usage. This feedlot does not wash cattle Administration and minor activities contribute in the order of 4% of the total energy usage. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

FIGURE 36 shows the total monthly energy usage at Feedlot E on a MJ/head on feed/month basis for the period March 2007 to February 2008.

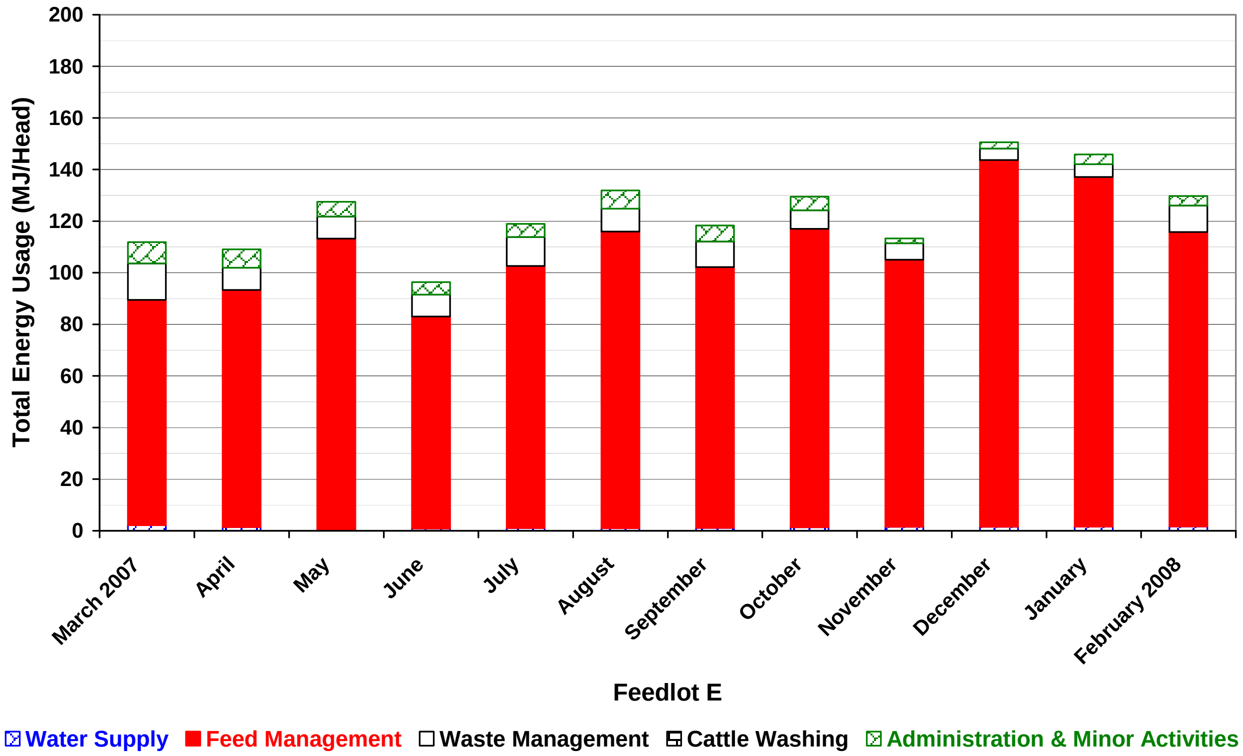



**Figure 29 – Monthly total energy usage at Feedlot E (MJ/head on feed/month)**

At Feedlot E, the total monthly energy use ranges from 95 to 151 MJ/head on feed/month. The total energy usage for the year is 1483 MJ/head on feed, slightly higher than the maximum figure of 1300 MJ/head on feed recorded by Davis and Watts (2006). Feed management is the single largest consumer of energy in the feedlot. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

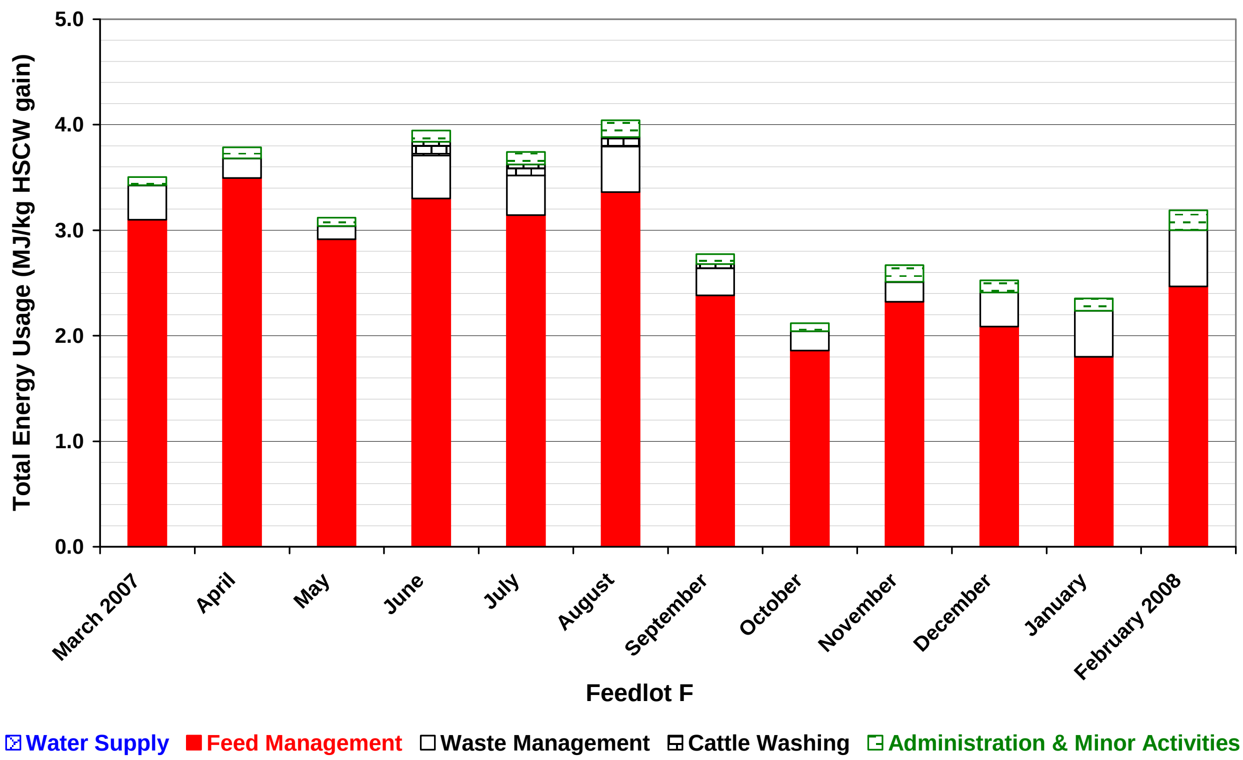



**Figure 30 – Monthly total energy usage at Feedlot F (MJ/kg HSCW gain)**

FIGURE 30 shows the total monthly energy usage at Feedlot F for the period March 2007 to February 2008. At Feedlot F, the total monthly energy use ranges from 2.1 (October 2007) to 4.1 MJ/kg HSCW gain (August 2007). Feed management is the largest single consumer of energy in the feedlot as expected and contributed between 1.8 to 3.5 MJ/kg HSCW gain or on average approximately 85 % of total usage. Waste management energy usage contributed between 0.12 MJ/kg HSCW gain (4 %) and 0.54 MJ/kg HSCW gain (17 %) of total energy usage, however on average represents 10% of the total energy usage. Water supply contributed an average of 0.006 MJ/kg HSCW gain or less than 0.2 % of total usage. This feedlot does not wash cattle. Administration and minor activities contribute in the order of 4% of the total energy usage. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

FIGURE 31 shows the total monthly energy usage at Feedlot F on a MJ/head on feed/month basis for the period March 2007 to February 2008.

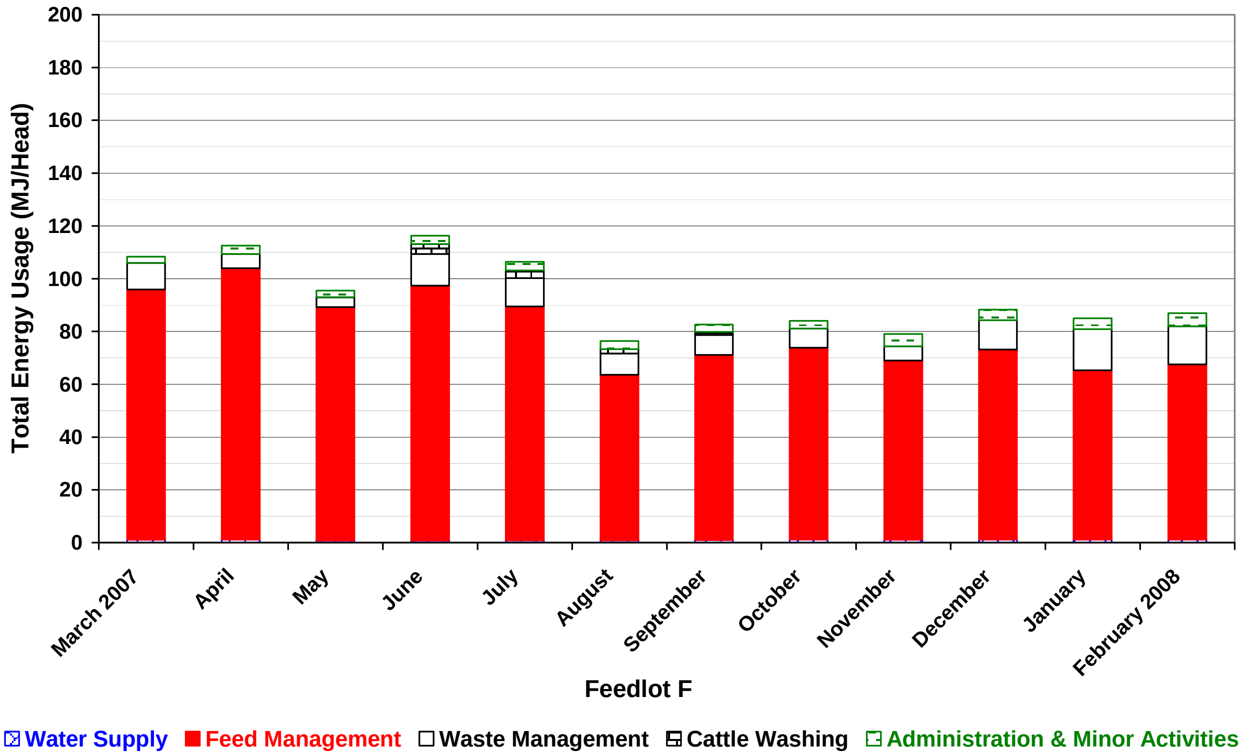



**Figure 31 – Monthly total energy usage at Feedlot F (MJ/head on feed/month)**

At Feedlot F, the total monthly energy use ranges from 75 to 115 MJ/head on feed/month. The total energy usage for the year is 1121 MJ/head, a figure slightly lower than that recorded by Sweeten et al. (1986) and Davis and Watts (2006). Feed management is the single largest consumer of energy in the feedlot. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

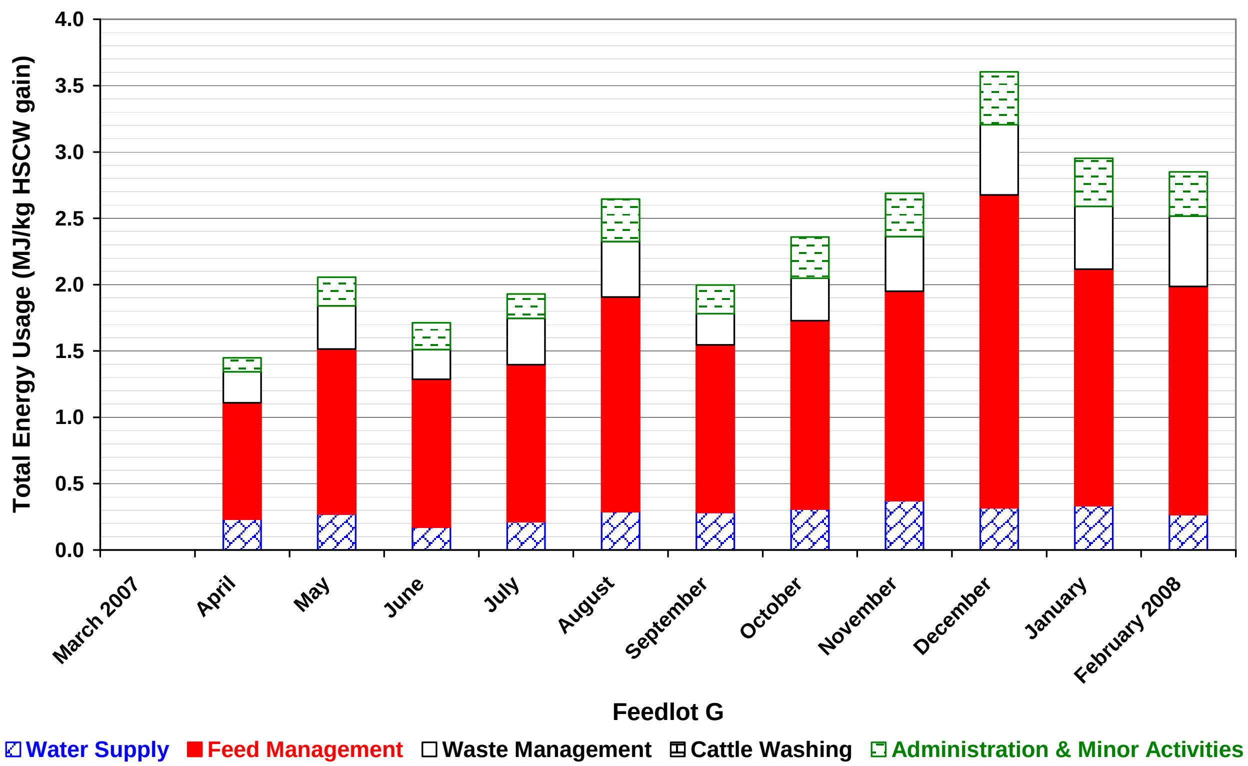



**Figure 32 – Monthly total energy usage at Feedlot G (MJ/kg HSCW gain)**

FIGURE 32 shows the total monthly energy usage at Feedlot G for the period March 2007 to February 2008. At Feedlot G, the total monthly energy use ranges from 1.4 (April 2007) to 3.6 MJ/kg HSCW gain (December 2007). Water supply contributed an average of 0.28 MJ/kg HSCW gain or approximately 13 % of total usage. Feed management is the largest single consumer of energy in the feedlot as expected and contributed between 0.88 to 2.4 MJ/kg HSCW gain or on average approximately 55 % of total usage. Waste management energy usage contributed between 0.22 MJ/kg HSCW gain (15 %) and 0.53 MJ/kg HSCW gain (21 %) of total energy usage, however on average represents 18% of the total energy usage. Administration and minor activities contribute in the order of 13% of the total energy usage. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

FIGURE 33 shows the total monthly energy usage at Feedlot G on a MJ/head on feed/month basis for the period March 2007 to February 2008.

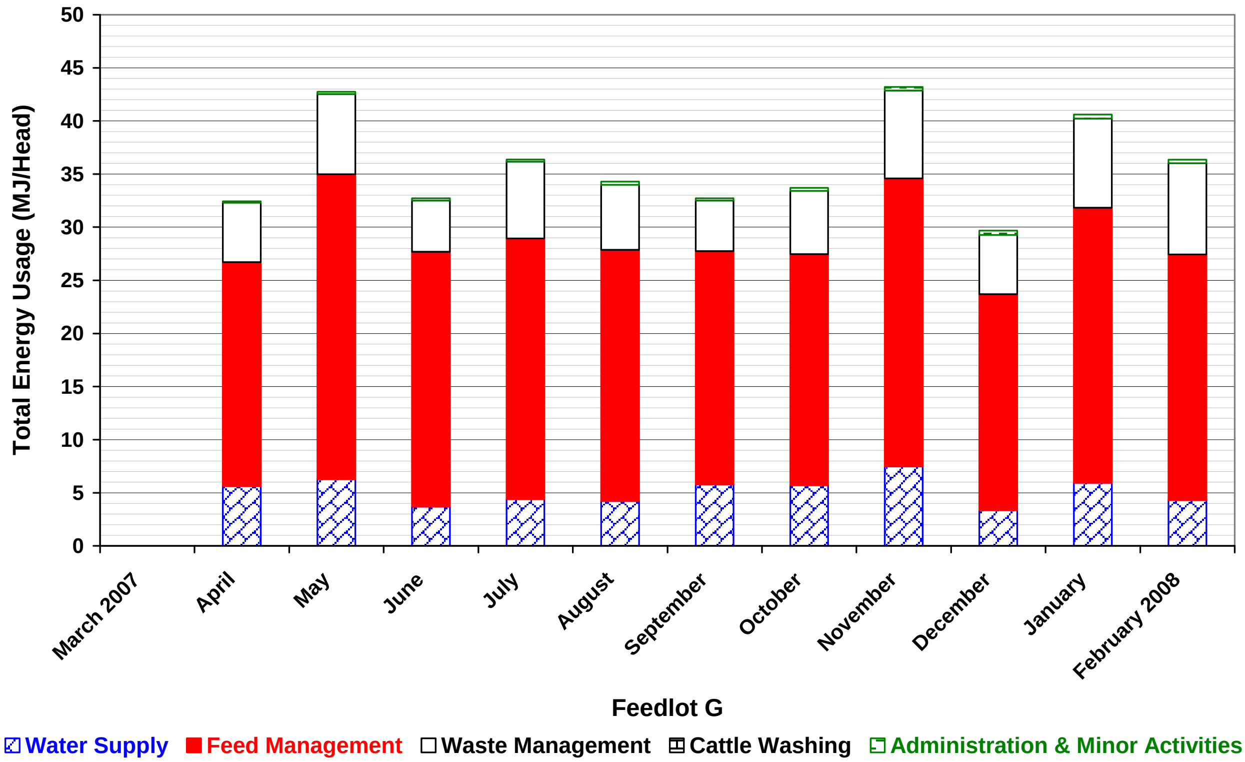



**Figure 33 – Monthly total energy usage at Feedlot G (MJ/head on feed/month)**

At Feedlot G, the total monthly energy use ranges from 30 to 43 MJ/head on feed/month. The total energy usage for the year is 444 MJ/head. Feed management is the single largest consumer of energy in the feedlot. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

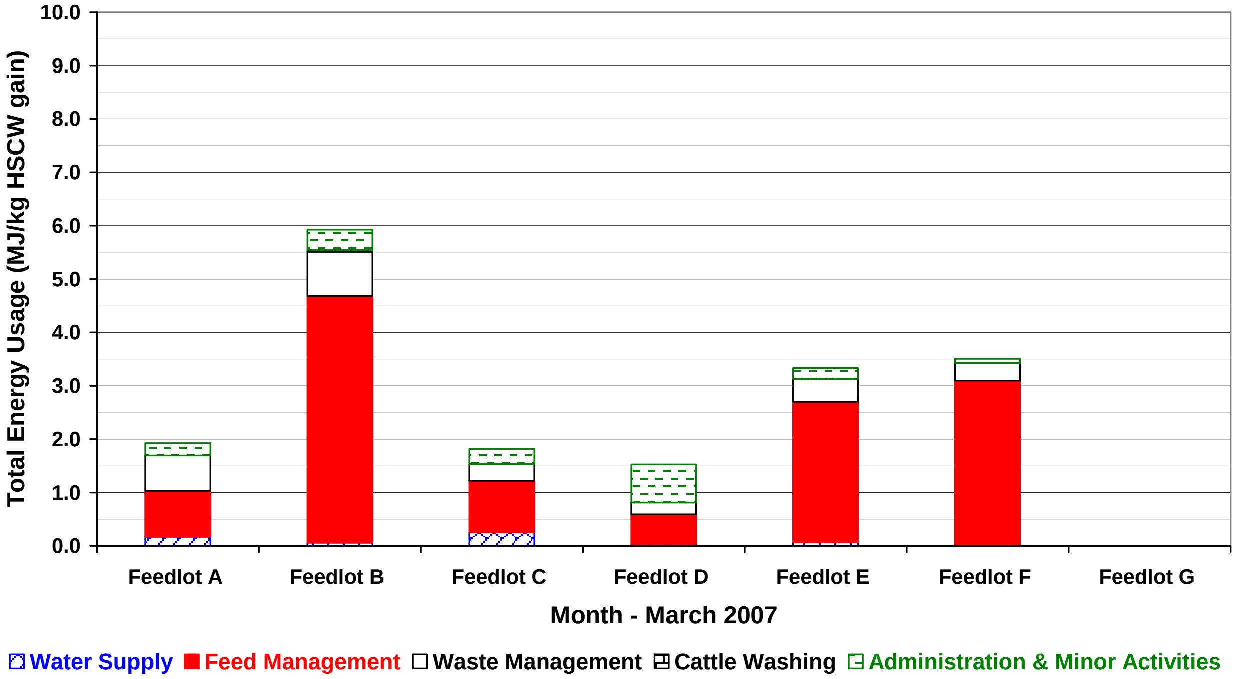



**Figure 34 – Total energy usage for March 2007 (MJ/kg HSCW gain)**

FIGURE 34 shows the total energy usage across all feedlots for March 2007. Total monthly energy use ranges from 1.0 to 5.9 MJ/kg HSCW gain and is primarily determined by the type of feed processing system in operation. The lowest energy usage was measured at Feedlot D (tempering only) and the highest at Feedlot B (steam flaking). Total energy usage was not recorded at Feedlot G during March 2007. Water supply energy consumption is dependent on the type of supply and reticulation system. Feedlots may access water from deep bores (Feedlot A) or source water from greater distances (Feedlot C) than feedlots on reticulated supply and /or gravity fed reticulation systems. Water supply energy usage ranged from 0.004 to 0.25 MJ/kg HSCW gain across all feedlots. Feed processing energy usage ranged from 0.56 (Feedlot D) to 4.6 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.22 to 0.83 MJ/kg HSCW gain. Administration and minor activities energy usage was found to range from 0.08 to 0.39 MJ/kg HSCW gain. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

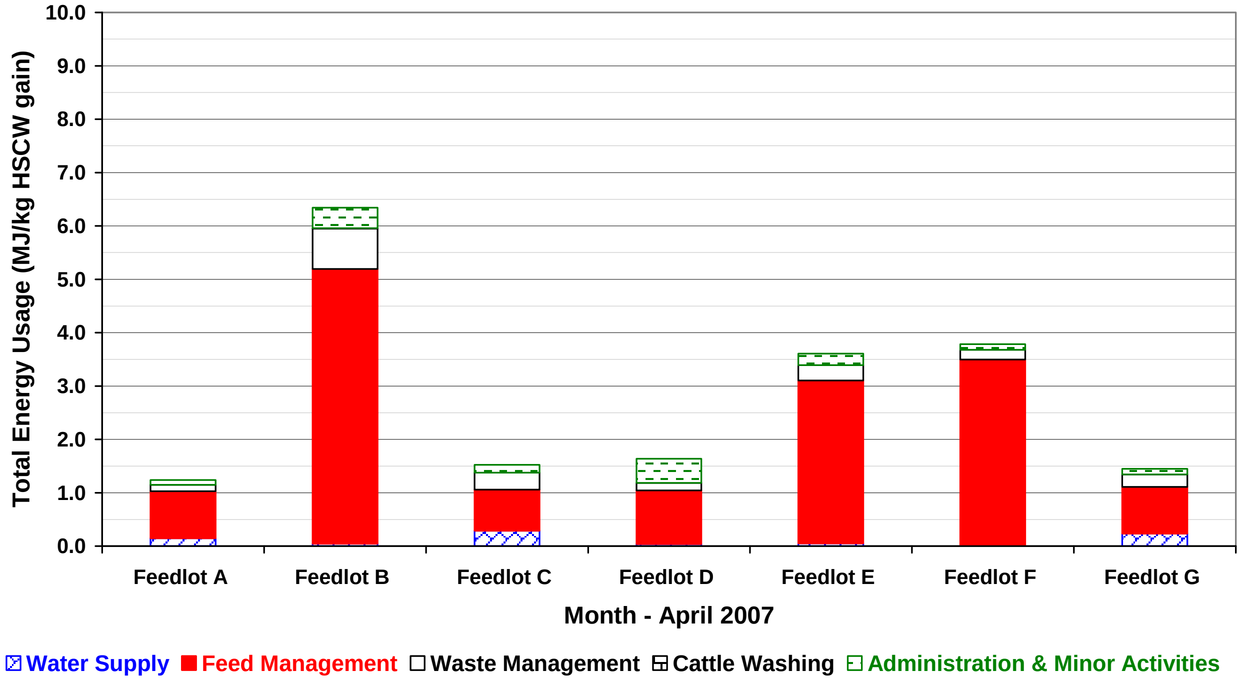



**Figure 35 – Total energy usage for April 2007 (MJ/kg HSCW gain)**

FIGURE 35 shows the total energy usage across all feedlots for April 2007. Total monthly energy use ranges from 1.25 to 6.4 MJ/kg HSCW gain, similar levels to March. The lowest energy usage was measured at feedlots A, C, D and G (reconstitution and tempering) with higher energy usage at feedlots B, E and F (steam flaking). Water supply energy consumption is dependent on the type of supply and reticulation system. Water supply energy usage ranged from 0.005 MJ/kg HSCW gain at Feedlot F to 0.29 MJ/kg HSCW gain at Feedlot C. Feed processing energy usage ranged from 0.77 (Feedlots A and G) to 5.15 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.12 to 0.76 MJ/kg HSCW gain. Administration and minor activities energy usage were found to range from 0.01 to 0.39 MJ/kg HSCW gain, similar levels when compared to March. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

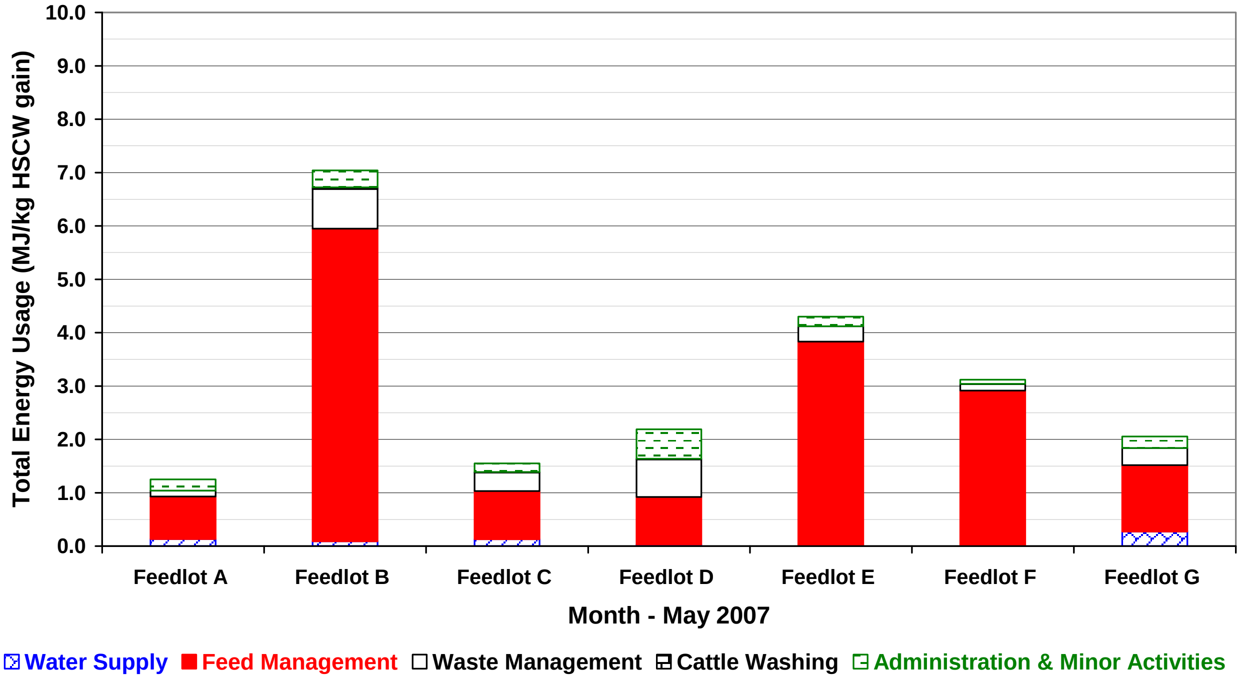



**Figure 36 – Total energy usage for May 2007 (MJ/kg HSCW gain)**

FIGURE 36 shows the total energy usage across all feedlots for May 2007. Total monthly energy use ranged from 1.25 to 7.0 MJ/kg HSCW gain. Feedlots B, D, E and G have slightly higher total energy usage then previously measured. The lowest energy usage was measured at feedlots A, C, D and G (reconstitution and tempering) with higher energy usage at feedlots B, E and F (steam flaking). For May 2007, water supply energy usage ranged from 0.004 MJ/kg HSCW gain at Feedlot F to 0.27 MJ/kg HSCW gain at Feedlot G. Feed processing energy usage ranged from 0.80 (Feedlot A) to 5.8 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.11 to 0.74 MJ/kg HSCW gain, a similar range to April. Energy usage within administration and minor activities was found to range from 0.08 to 0.32 MJ/kg HSCW gain. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

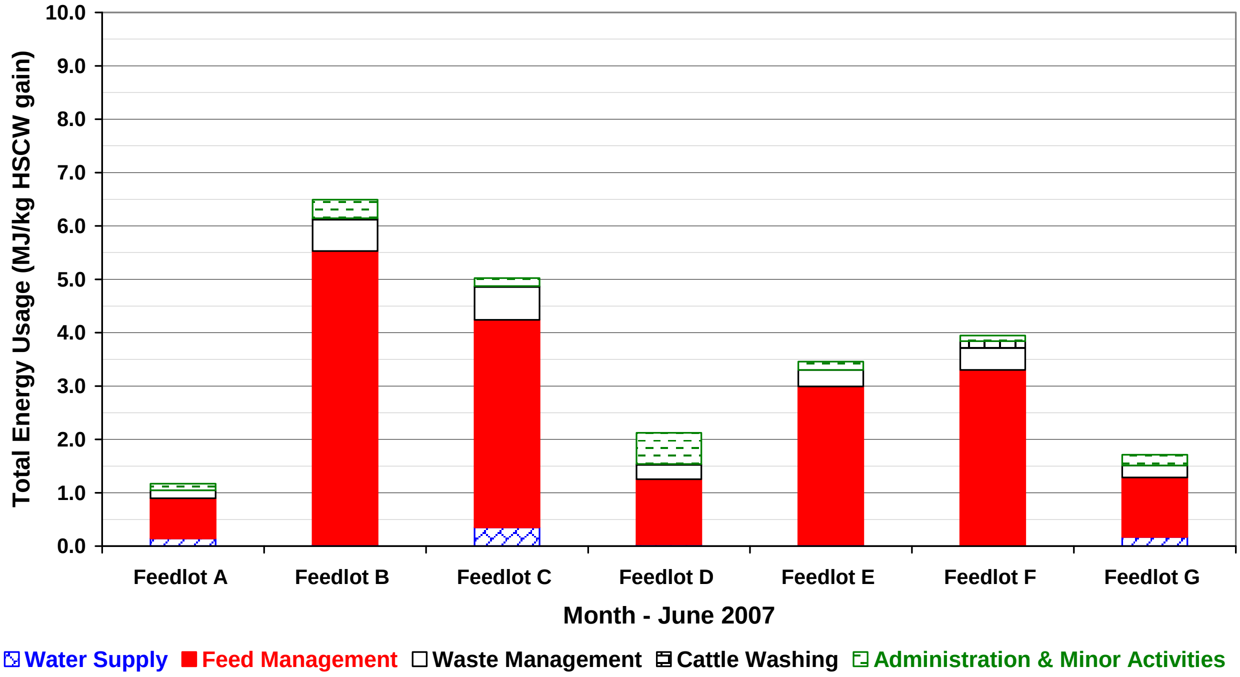



**Figure 37 – Total energy usage for June 2007 (MJ/kg HSCW gain)**

FIGURE 37 shows the total energy usage across all feedlots for June 2007. Total monthly energy use ranged from 1.15 to 6.5 MJ/kg HSCW gain. The impact of an energy dominant feed processing system on total energy usage can be seen with Feedlot C. In June a steam flaking system was commissioned and hence energy usage has increased considerably from 1.3 to 4.7 MJ/kg HSCW gain. Water supply energy usage ranged from 0.007 MJ/kg HSCW gain at Feedlot F to 0.35 MJ/kg HSCW gain at Feedlot C. Feed processing energy usage ranged from 0.75 (Feedlot A) to 5.8 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.11 to 0.74 MJ/kg HSCW gain, a similar range to April. Administration and minor activities energy usage was found to range from 0.10 to 0.35 MJ/kg HSCW gain. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

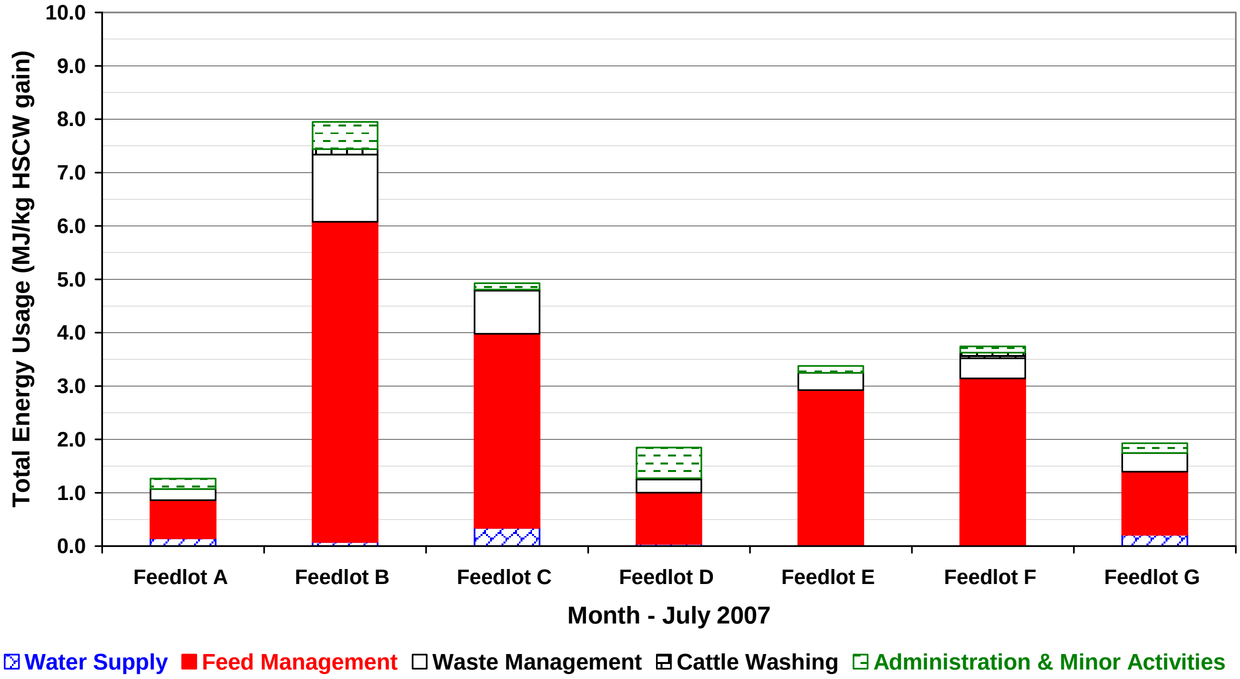



**Figure 38 – Total energy usage for July 2007 (MJ/kg HSCW gain)**

FIGURE 38 shows the total energy usage across all feedlots for July 2007. Total monthly energy use ranged from 1.25 to 8.0 MJ/kg HSCW gain. Feedlot B has a higher total energy usage than previously measured, whilst Feedlot D has a slightly lower total energy usage than previously measured. The lowest energy usage was measured at Feedlots A, D and G (reconstitution and tempering) with higher energy usage at feedlots B, C, E and F (steam flaking). For July 2007, water supply energy usage ranged from 0.01 MJ/kg HSCW gain at Feedlot F to 0.34 MJ/kg HSCW gain at Feedlot C. Feed management energy usage ranged from 0.71 (Feedlot A) to 6.0 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.21 to 1.26 MJ/kg HSCW gain, a higher range than previously measured. Cattle washing energy usage ranges from 0.02 MJ/kg HSCW gain at Feedlots C and D to 0.1 MJ/kg HSCW gain at Feedlot B. Energy usage within administration and minor activities was found to range from 0.12 to 0.51 MJ/kg HSCW gain. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

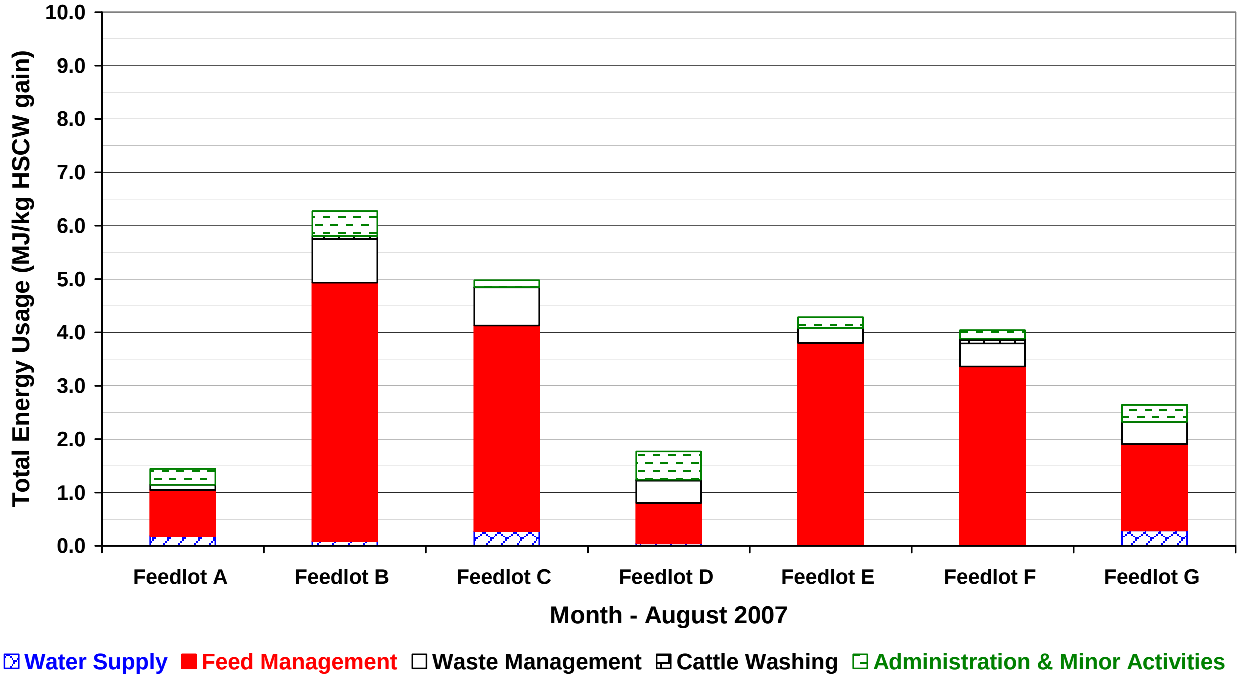



**Figure 39 – Total energy usage for August 2007 (MJ/kg HSCW gain)**

FIGURE 39 shows the total energy usage across all feedlots for August 2007. Total monthly energy use ranged from 1.5 to 6.3 MJ/kg HSCW gain. Feedlot B has significantly reduced its total energy usage from 8 to 6.25 MJ /kg HSCW gain, whilst feedlots E and G have slightly increased its total energy usage when compared to July. The lowest energy usage was measured at Feedlots A, D and G (reconstitution and tempering) with higher energy usage at feedlots B, C, E and F (steam flaking). There is still a large range in feed management energy usage between feedlots with steam flaking. In these feedlots, feed management energy usage ranges from 3.4 MJ/kg HSCW gain at Feedlot F to 4.9 MJ/kg HSCW gain at Feedlot B. Water supply energy usage is similar to previous months and ranged from 0.01 MJ/kg HSCW gain at Feedlot F to 0.29 MJ/kg HSCW gain at Feedlot G. Waste management energy usage has the most variability between months and feedlots as this activity is dependent on climatic conditions and management strategies. For August, it ranged from 0.10 to 0.82 MJ/kg HSCW gain. Cattle washing energy usage ranges from 0.01 MJ/kg HSCW gain at Feedlots C and D to 0.09 MJ/kg HSCW gain at Feedlot F. Energy usage within administration and minor activities was found to range from 0.09 to 0.47 MJ/kg HSCW gain. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

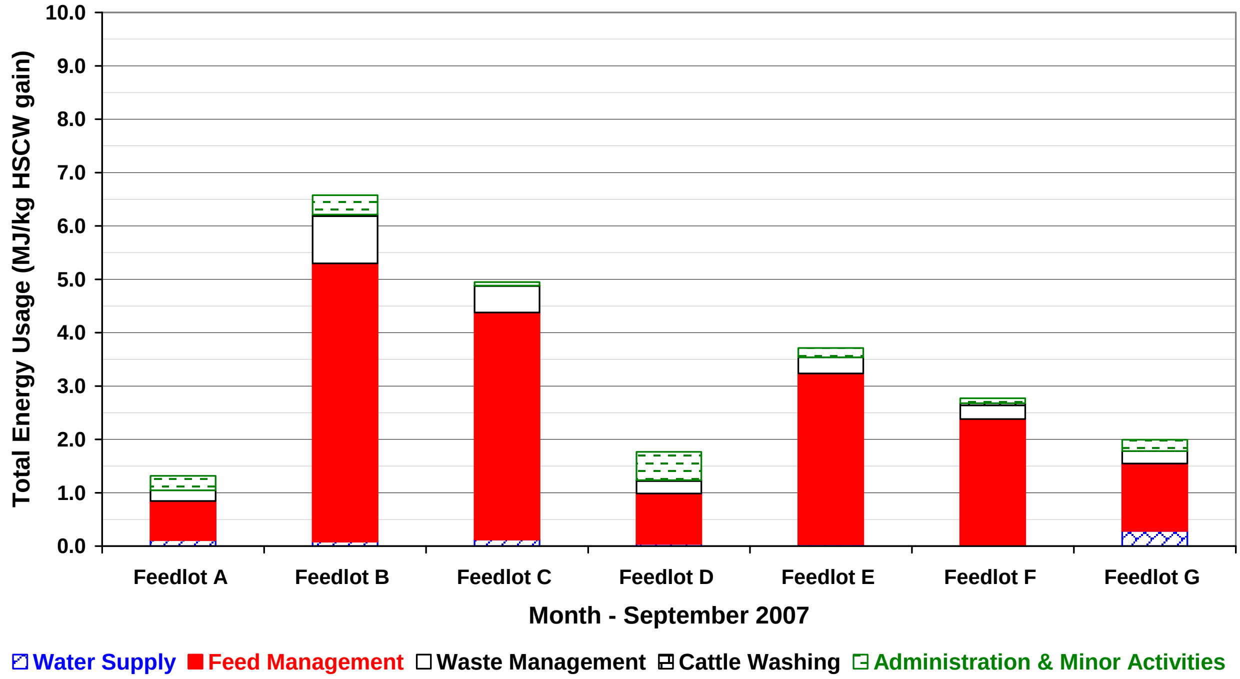



**Figure 40 – Total energy usage for September 2007 (MJ/kg HSCW gain)**

FIGURE 40 shows the total energy usage across all feedlots for September 2007. Total monthly energy use ranged from 1.3 to 6.6 MJ/kg HSCW gain, a similar range to August. Water supply energy usage is similar to previous months in all feedlots with the exception of Feedlot G which has decreased from 0.28 MJ/kg HSCW gain to 0.12 MJ/kg HSCW gain. Feed management energy usage ranged from 0.73 (Feedlot A) to 5.2 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.2 to 0.88 MJ/kg HSCW gain a similar range to previous months. Cattle washing energy usage ranges from 0.001 MJ/kg HSCW gain at Feedlot C to 0.40 MJ/kg HSCW gain at Feedlot F. Similar energy usage levels to previous months was measured within administration and minor activities and was found to range from 0.07 to 0.36 MJ/kg HSCW gain. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

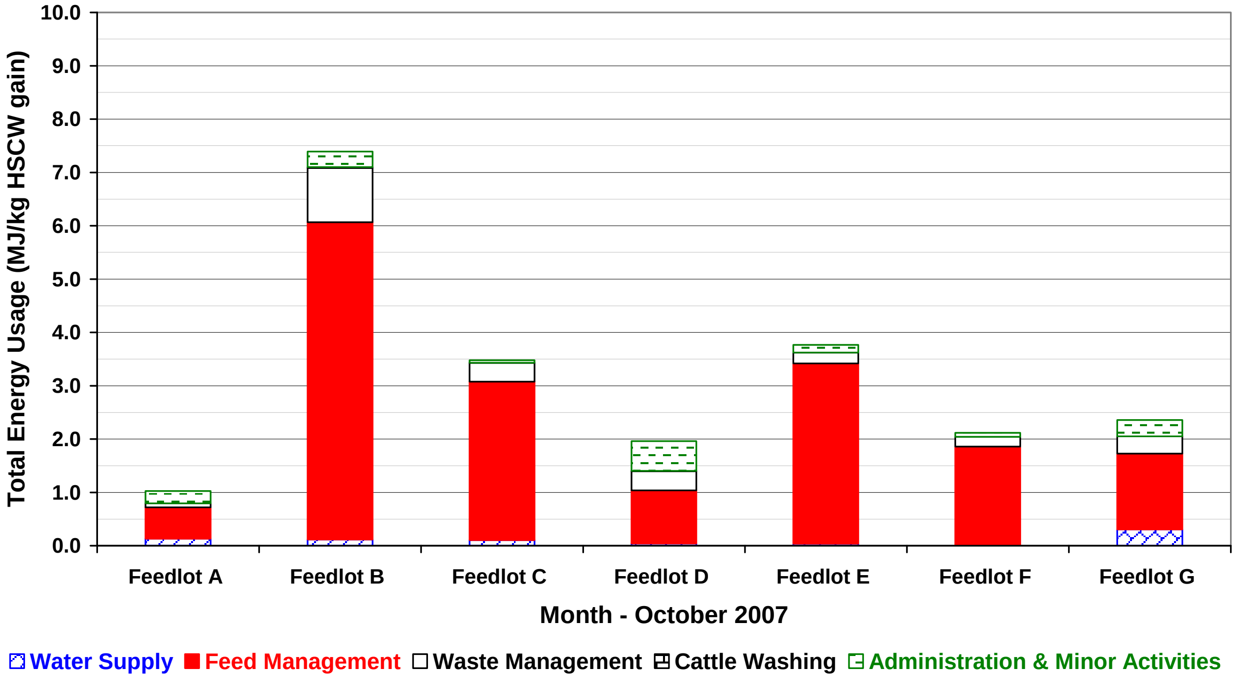



**Figure 41 – Total energy usage for October 2007 (MJ/kg HSCW gain)**

The total energy usage across all feedlots for October 2007 is shown in FIGURE 41. Total monthly energy use ranged from 1 to 7.4 MJ/kg HSCW gain. Feedlots A, C and F have slightly reduced their total energy usage when compared with previous months, whilst feedlots B, D, E and G have increased their total usage when compared with September levels. Water supply energy usage is similar to previous months in all feedlots and ranges from 0.003 MJ/kg HSCW gain to 0.31 MJ/kg HSCW gain. Feed management energy usage ranged from 0.59 (Feedlot A) to 5.95 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.07 to 1.02 MJ/kg HSCW gain at Feedlot B. Cattle washing energy usage ranges from 0.001 MJ/kg HSCW gain at Feedlot C to 0.017 MJ/kg HSCW gain at Feedlot B. Similar energy usage levels to previous months was measured within administration and minor activities and was found to range from 0.05 to 0.31 MJ/kg HSCW gain. Feedlot B continues to record the highest total energy usage per kg HSCW gain across all the feedlots, this in part is due to this feedlot having long fed cattle with low average daily gain. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

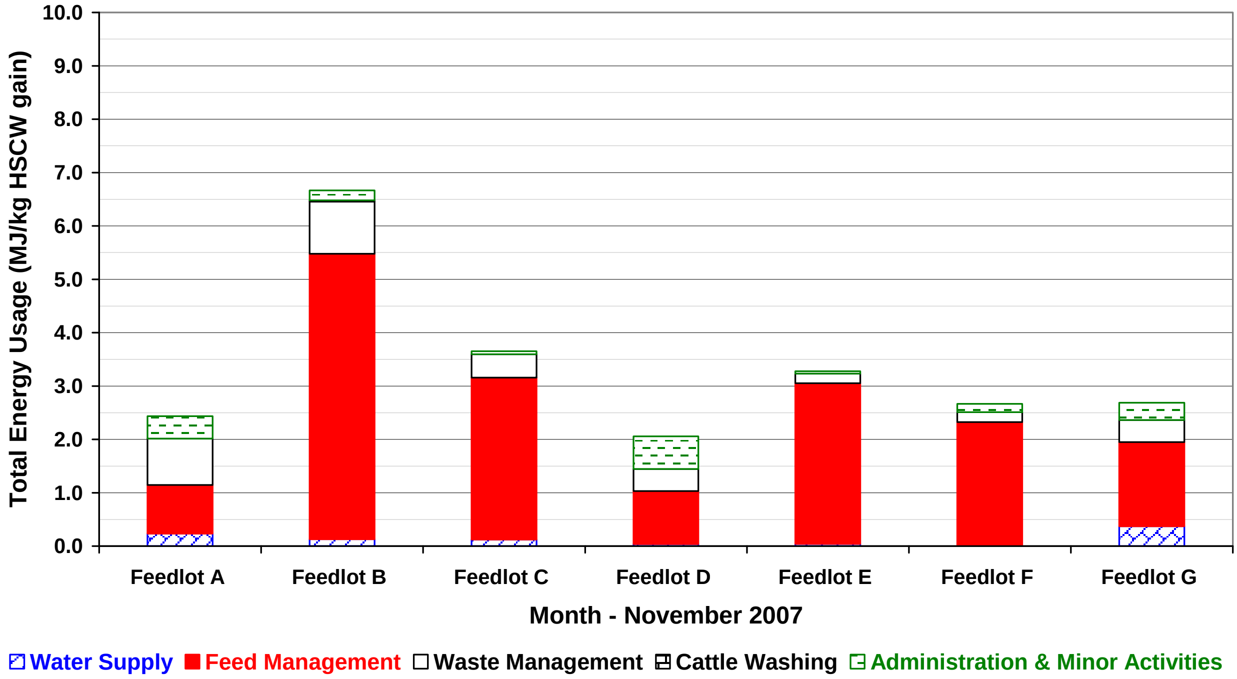



**Figure 42 – Total energy usage for November 2007 (MJ/kg HSCW gain)**

The total energy usage across all feedlots for November 2007 is shown in FIGURE 42. Total monthly energy use ranged from 2.5 to 6.7 MJ/kg HSCW gain. Feedlot A has doubled its energy usage from October, driven by a marked increase in waste management, a resultant of the high level of pen cleaning undertaken during November. Feedlots F and G have slightly increased their total energy usage when compared with previous months, whilst feedlots C and D are similar. Feedlot B and E has reduced their total usage when compared with October levels, due to a reduction in feed management and administration and minor activities usage. Water supply energy usage is similar to previous months and ranges from 0.004 MJ/kg HSCW gain to 0.37 MJ/kg HSCW gain. Feed management energy usage ranged from 0.9 (Feedlot A) to 5.4 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.18 MJ/kg HSCW gain at Feedlot F to 0.98 MJ/kg HSCW gain at Feedlot B. Cattle washing had ceased for the season at all feedlots except Feedlot B. where a energy usage of 0.02 MJ/kg HSCW gain was measured. Similar energy usage levels to previous months was measured within administration and minor activities and was found to range from 0.05 to 0.38 MJ/kg HSCW gain. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

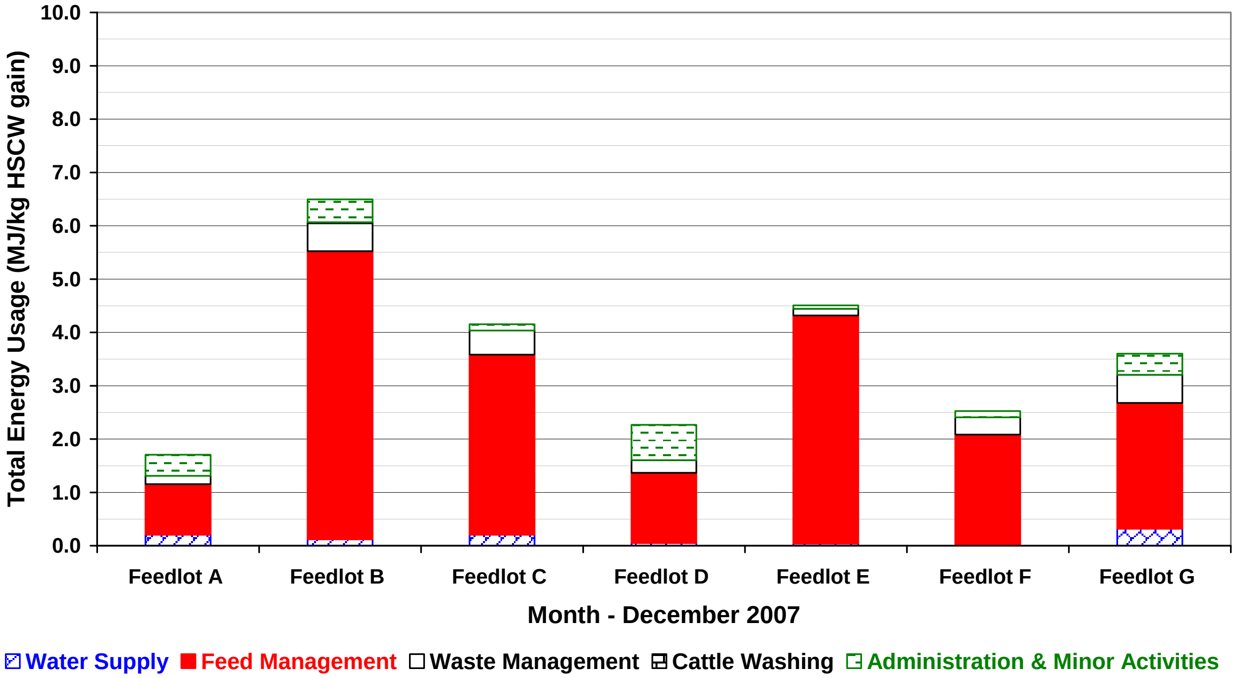



**Figure 43 – Total energy usage for December 2007 (MJ/kg HSCW gain)**

The total energy usage across all feedlots for December 2007 is shown in FIGURE 43. Total monthly energy use ranged from 1.7 MJ/kg HSCW gain at Feedlot A to 6.5 MJ/kg HSCW gain at Feedlot B. The impact of lower cattle numbers on feed and hence lower HSCW gain may be contributing to the increases in total energy usage when compared with previous months at feedlots E and G. Feedlot A has reduced their total usage when compared with November levels, due to a reduction in waste management energy usage. Water supply energy usage is similar to previous months and ranges from 0.004 MJ/kg HSCW gain to 0.32 MJ/kg HSCW gain. Feed management energy usage ranged from 0.95 (Feedlot A) to 5.4 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.13 MJ/kg HSCW gain at Feedlot E to 0.53 MJ/kg HSCW gain at Feedlot G. In December cattle were washed only at all Feedlot B, where an energy usage of 0.02 MJ/kg HSCW gain was measured. Similar energy usage levels to previous months was measured within administration and minor activities and was found to range from 0.06 to 0.43 MJ/kg HSCW gain. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

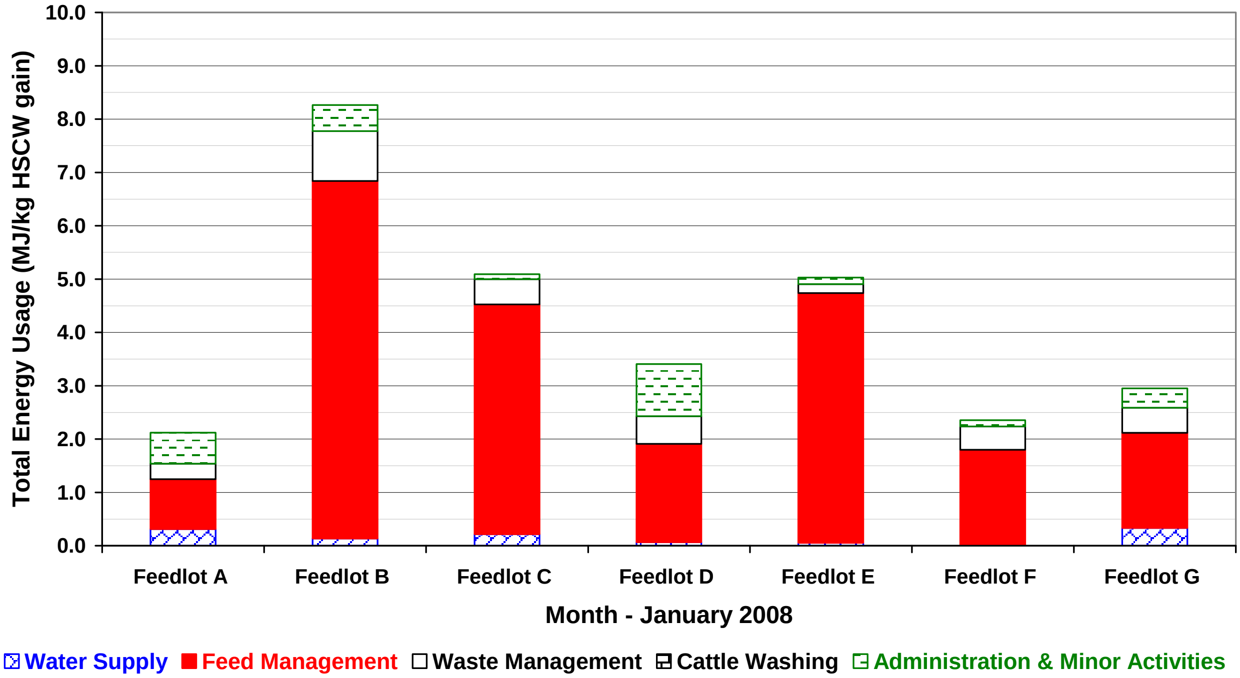



**Figure 44 – Total energy usage for January 2008 (MJ/kg HSCW gain)**

FIGURE 44 shows the total energy usage across all feedlots for January 2008. Total monthly energy use ranged from 2.1 MJ/kg HSCW gain at Feedlot A to 8.25 MJ/kg HSCW gain at Feedlot B. Feedlot B has increased their total usage from 6.5 to 8.25 MJ/kg HSCW gain when compared with December levels. Water supply energy usage is similar to previous months and ranges from 0.004 MJ/kg HSCW gain to 0.33 MJ/kg HSCW gain. Feed management energy usage ranged from 0.94 (Feedlot A) to 6.7 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.17 MJ/kg HSCW gain at Feedlot E to 0.94 MJ/kg HSCW gain at Feedlot B. All feedlots had ceased cattle washing by January 2008. Similar energy usage levels to previous months was measured within administration and minor activities and was found to range from 0.09 to 0.57 MJ/kg HSCW gain. For Feedlots A, D and E, hotter temperatures in January has led to an increase in administration (cooling) energy usage. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

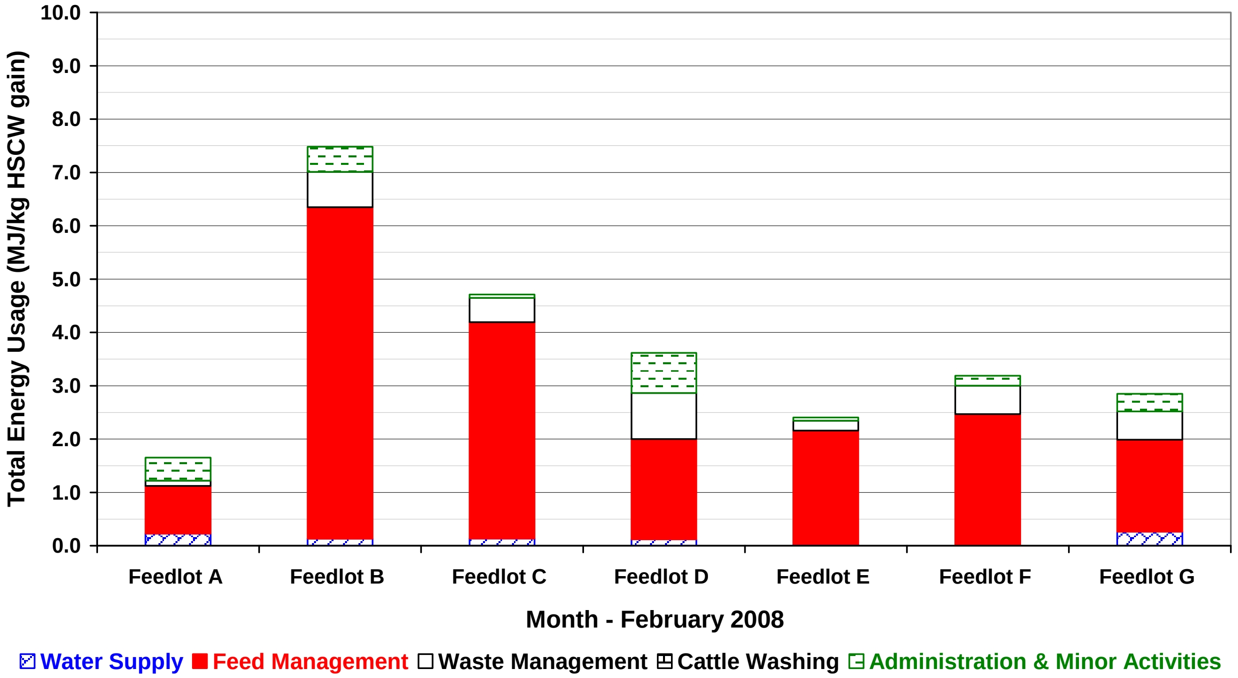



**Figure 45 – Total energy usage for February 2008 (MJ/kg HSCW gain)**

Figure 45 shows the total energy usage across all feedlots for February 2008. Total monthly energy use ranged from 1.6 MJ/kg HSCW gain at Feedlot A to 7.5 MJ/kg HSCW gain at Feedlot B. Feedlot E has almost halved their total energy usage for February when compared to January levels. This is due to a large increase in HSCW gain for this month.

Water supply energy usage is similar to previous months and ranges from 0.004 MJ/kg HSCW gain to 0.27 MJ/kg HSCW gain. Feed management energy usage ranged from 0.89 (Feedlot A) to 6.2 (Feedlot B) MJ/kg HSCW gain. Waste management energy usage ranged from 0.1 MJ/kg HSCW gain at Feedlot A to 0.87 MJ/kg HSCW gain at Feedlot D. There was no cattle washing in February 2008. Administration and minor activities energy usage levels had reduced slightly in February when compared to January readings and were found to range from 0.06 to 0.47 MJ/kg HSCW gain. For Feedlots A, D and E, cooler temperatures in February led to an decrease in administration (cooling) energy usage. Further discussion on activity energy usage is presented in Sections 5.3 to 5.7.

The monthly variation and variation between feedlots when standardised on a per kg of HSCW can be attributed to a number of factors. These include the design and layout of the water supply system, feed processing and feed delivery system, cattle market types (short fed v long fed) and management operations. Energy usage is less dependent on climatic variation when compared with water usage. Further discussion on individual activity energy usage is presented in the following sections.

## 5.3 Water supply energy usage

FIGURE 46 illustrates the average water supply energy consumption on a MJ/head on feed/month basis for the seven feedlots. Water supply energy usage has been divided into supply (delivery from source) and reticulation around the feedlot (secondary pumping). The water supply systems ranged from combinations of delivery and gravity fed, delivery and reticulation, delivery, reticulation and gravity fed systems.

The minimum and maximum energy usage per head for any one month is presented. Note that feedlot numbering in this section does not match the numbering in previous sections to maintain anonymity for the participating feedlots. Whilst a summary is provided in this section, complete individual feedlot monthly water supply energy usage figures on a per head basis are presented in Appendix A.

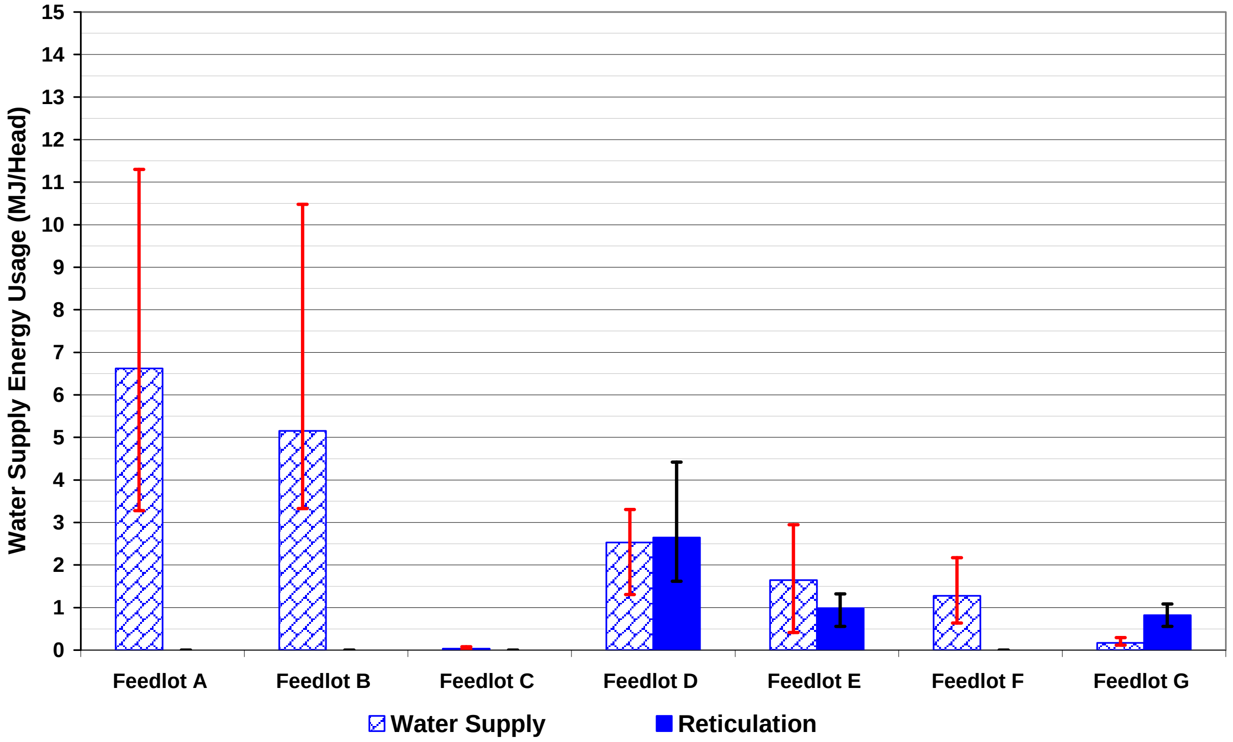



**Figure 46 – Water supply energy usage (MJ/head on feed/month)**

The average total water supply energy usage across all feedlots for March 2007 to February 2008 ranged from 0.04 MJ/head on feed/month at Feedlot C to 6.6 MJ/head on feed/month at Feedlot A, with an average in the order of 2.5 MJ/head on feed/month. The data presented is based on total kWh used in water supply and or reticulation. In most cases, total kWh is made up of a combination of off-peak and peak electricity tariffs. Therefore, only an approximate cost of supply can be gained from this figure, if desired.

Water supply energy usage between feedlots is dependent on a number of factors, including depth to groundwater and distance to supply. Within feedlots, water supply energy usage is directly proportional to the water pumped per month. Feedlot A had the highest average water supply energy consumption due to sourcing its water from bores located some distance to the feedlot and pumping against high head. Feedlots A, B, C and F have gravity fed water reticulation systems. Feedlot D demonstrates the additional energy usage with having to deliver water to the pens via a pumping system compared with a gravity supply system. In this case, energy consumed in delivering water to the pens is greater than supplying water to buffer storage facilities. Future consideration should be given to gravity supply if possible. For example, an energy usage of 2.5 MJ/head on feed/month for a feedlot with 10,000 head on feed will utilise 300000 MJ/year or approximately 83,000 kWh in direct electricity usage. At 0.15c/kWh, this equates to about $12,500/year.

An indication of the monthly variability in water supply energy usage can be gained through comparison of the maximum, minimum and average consumption levels. FIGURE 46 shows that the majority of feedlots, with the exception of feedlots C and G, have a degree of variability in energy usage. Feedlot C has a consistent usage with only one or two months of high usage. Conversely, Feedlot G has a less variability. The variability in energy usage can be explained by the variation in monthly total water usage.

## 5.4 Feed management energy usage

Feed management energy usage has been proportioned into feed processing and feed delivery usage. The energy used within each respective activity is presented in the following sections.

### 5.4.1 Feed processing energy usage

FIGURE 47 illustrates the average feed management processing energy usage on a tonne of grain processed basis for the seven feedlots. In this section, as feed processing energy used is expressed on a per tonne of grain basis, it only includes the electricity and gas used in grain storage, movement and preparation. It does not include the energy used in tub grinding. Energy used in tub grinding is included in Appendix C, Section C.1.

The minimum and maximum feed processing water usage on a tonne of grain processed basis for any one month is also presented. The feedlot numbering in this section does not match the numbering in previous sections to maintain anonymity for the participating feedlots. Whilst a summary is provided in this section, complete individual feedlot monthly feed processing energy usage on a MJ used per tonne of ration (including tub grinding) and grain processed basis are presented in Appendix C, Section C.1.

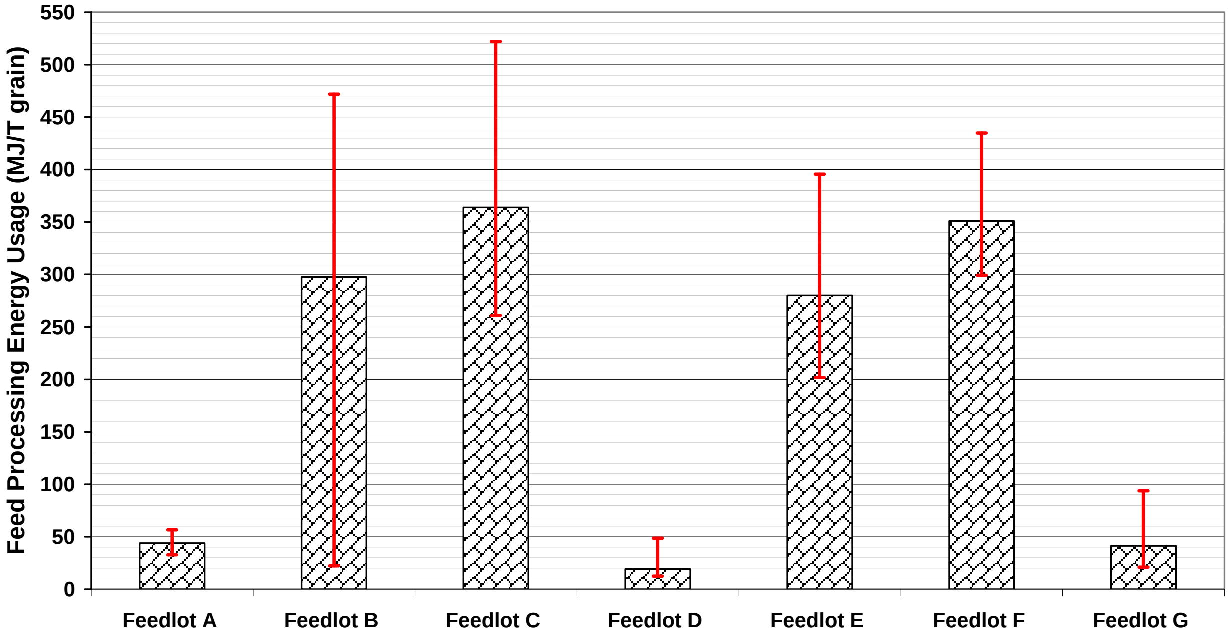



**Figure 47 – Total feed processing energy usage (MJ/t grain)**

Feed processing energy usage is the largest single consumer of energy in feedlots. The average feed processing energy usage measured ranges from 20 to 365 MJ/t grain processed. Three different feed processing systems are represented within the seven feedlots. Feedlots B, C, E and F steam flake grain whilst Feedlots A, D and F either temper only or temper and reconstitute grain. For feed processing systems other than steam flaking, average energy usage is typically less than 50 MJ/t grain processed. For steam flaking, the total energy usage ranges from 280 to 365 MJ/t grain processed. Hence, there is a large variation between feed processing systems and between feedlots with the same system.

An indication of the monthly variability in feed processing energy usage can be gained through comparison of the maximum, minimum and average consumption levels. FIGURE 47 shows that, at the majority of feedlots with the exception of feedlots A, D and G, there is a large variability in energy usage. In some cases, e.g. Feedlot E, there is a 100% difference between minimum and maximum monthly usage. The variation in Feedlot B can be explained by a change in feed processing system during the study period from tempering to steam flaking. In addition, the lower average energy usage in Feedlot B, when compared with Feedlots C, E and F, may be attributed to the newer technology being more efficient. Feedlot D has a consistent usage with only one or two months of high usage. Conversely, Feedlot A has a less variability. For steam flaking systems, a review of individual feedlot monthly feed processing data from Appendix C.1, there is an increase in energy usage during the cooler winter months. Hence, more energy is required to heat water and increased heat transfer losses. Setup and operation of feed processing systems will also influence total energy usage.

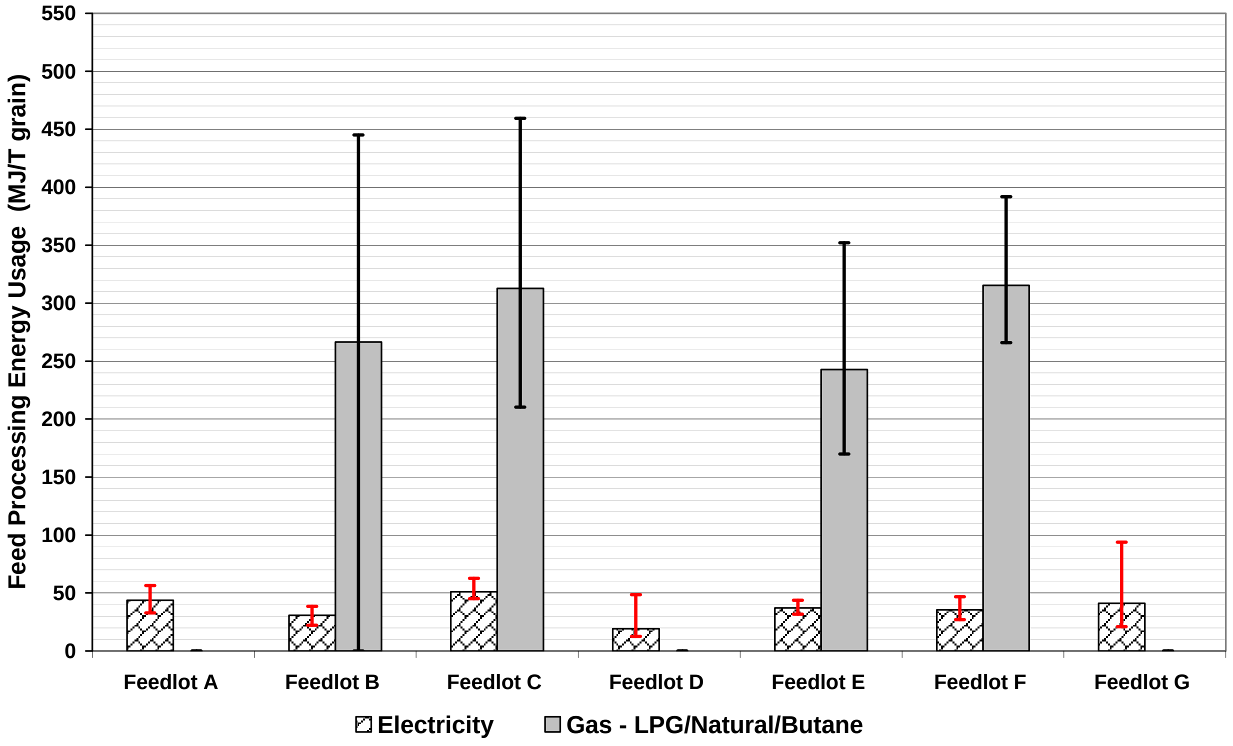



**Figure 48 – Feed processing component energy usage (MJ/t grain)**

At all feedlots, the feed processing energy usage was able to be divided into that consumed in electricity usage (grain delivery, movement and milling) and gas usage for boiler fuel in steam flaking systems. Note that the feedlot numbering in FIGURE 48 is consistent with the numbering in FIGURE 47. FIGURE 48 illustrates the average feed processing component energy usage on a tonne of grain-processed basis for the seven feedlots.

The average feed processing electricity energy usage measured ranges from 20 to 50 MJ/t grain processed. Feedlots B and D have an average electricity energy usage of 20 MJ/t grain. In one month, Feedlot D used 50 MJ/t grain. The remaining feedlots have electricity energy usage between 40 and 50 MJ/t grain processed. The variation in electricity energy usage may be attributed to monthly variation in grain delivery, movement and storage and milling efficiency (tonnes per mill). Note that in the majority of feedlots, the electricity used in grain delivery and storage could not be partitioned from total feed mill electricity usage.

For steam flaking systems, the average gas energy usage measured ranges from 240 to 315 MJ/t grain processed. There were three types of gases used within the four feedlots with steam flaking systems. These included LPG, butane and natural gas. All of these gas sources have different calorific values (heating content) and pricing structures. Some of the variation in gas usage can be attributed to heating efficiency during winter months.

### 5.4.2 Feed delivery energy usage

FIGURE 49 illustrates the average feed delivery energy usage on a tonne of ration delivered for the seven feedlots. In this section, feed delivery energy use comprises electricity used by stationary mixers, diesel consumed by loaders during feed loading and by feed trucks delivering ration to pens where appropriate.

The minimum and maximum feed processing water usage on a tonne of ration delivered basis for any one month is presented. The feedlot numbering in this section is consistent with the numbering is Section 5.4.1. Whilst a summary is provided in this section, complete individual feedlot monthly feed delivery energy usage on a MJ used per tonne of ration delivered basis are presented in Appendix C, Section C.2.

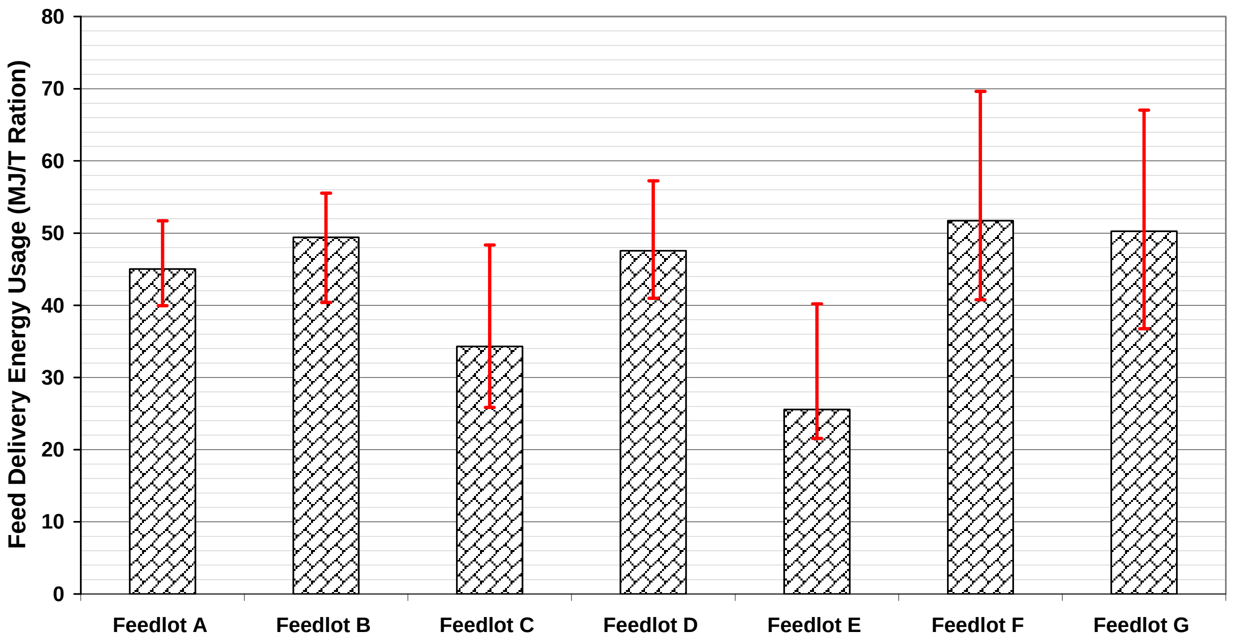



**Figure 49 – Total feed delivery energy usage (MJ/t ration)**

The average feed delivery energy usage measured ranges from 26 to 52 MJ/t ration delivered. A number of different feed delivery systems are represented within the seven feedlots. This includes stationary mixing, bunker system, batch-boxes and a number of varying combinations in mobile equipment. Mobile equipment combinations included tractor/trailed mixer units, ROTO-mix trucks (various capacities and number), loaders (number, no of ingredients and bucket capacities) and screw mixer trucks.

Feedlots A, B, F and G have an average feed delivery energy usage measured range from 45 to 52 MJ/t ration delivered. Feedlot C (34 MJ/t ration) and Feedlot E (26 MJ/t ration) have considerably less energy usage when compared with the remaining feedlots. Feedlot E uses, on average, half of the energy of the highest average feed delivery energy usage (Feedlot F). Whilst feed delivery energy usage is dependent on the system and equipment utilised, pen layout and feed-out method also influences the energy used. At Feedlot E, feed delivery is undertaken with two primary ROTO-Mix trucks with a combined horsepower of 535 hp (26 hp per tonne capacity) and cattle are fed twice per day. The hp per tonne capacity for Feedlot C is similar to Feedlot E. Feedlot E delivers finisher rations to consecutive rows and pens thus minimising travel distance. This approach may be a plausible explanation for the lower energy usage measured.

An indication of the monthly variability in feed processing energy usage can be gained through comparison of the maximum, minimum and average consumption levels. FIGURE 49 shows that, at the majority of feedlots with the exception of Feedlot E, there is a large variability in energy usage. In some cases, such as Feedlots C and D, there is close to a 100% difference between minimum and maximum monthly usage.

The results from the feed delivery energy usage figures show that there appears to be little energy efficiency gained from economies of scale with larger feedlots.

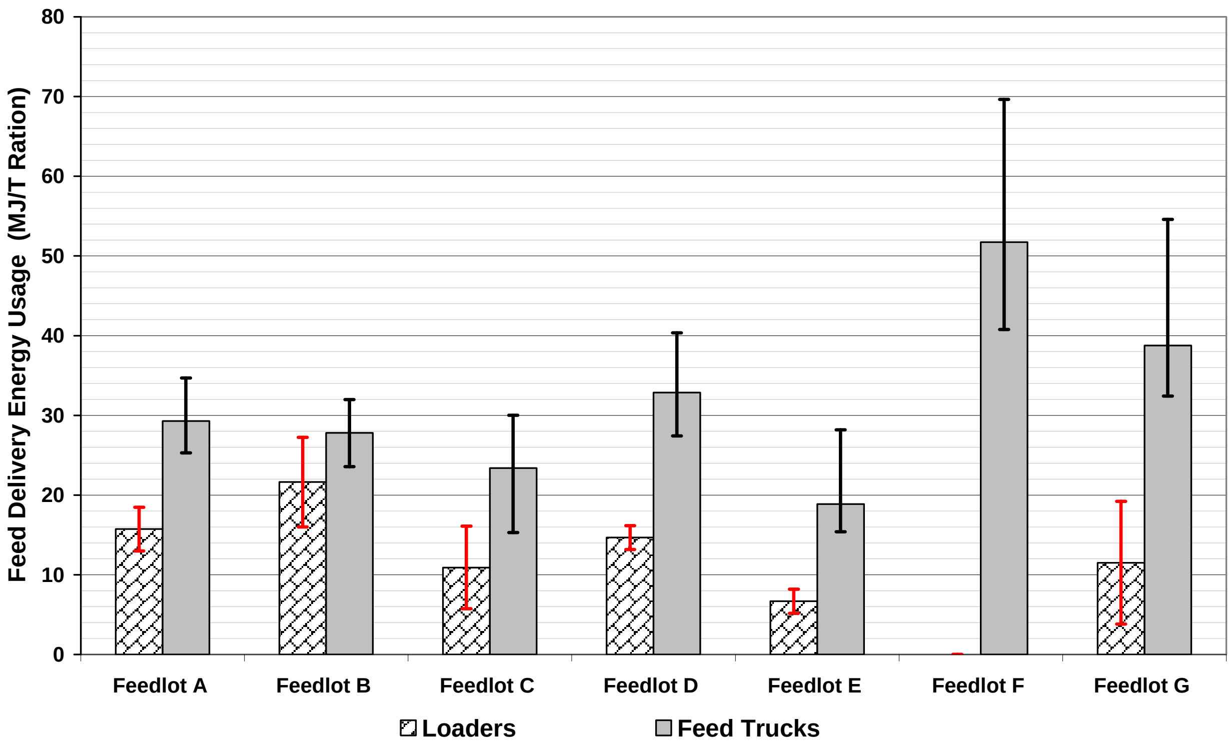



**Figure 50 – Feed delivery component energy usage (MJ/t ration)**

At all feedlots, with the exception of Feedlot F, the total feed delivery energy usage was able to be divided into that consumed during loading of commodities and that used by the mobile equipment during delivery. The feedlot numbering in FIGURE 50 is consistent with the numbering in FIGURE 49. FIGURE 50 illustrates the average feed delivery component energy usage on a tonne of ration delivered for the seven feedlots.

The average energy usage by loaders ranges from 7 to 22 MJ/t ration delivered. The energy used by loaders is dependent on a number of factors including the size of loader, bucket capacity, number of ingredients loaded and the other feed related activities that the loader/s may need to undertake. Other feed related activities may include transporting hay/straw from storage areas to tub grinders, silage from silage pits, high moisture grain from storage areas etc.

The average energy usage by feed delivery equipment ranges from 19 to 39 MJ/t ration delivered. The energy used by feed delivery equipment is dependent on a number of factors including the number, volumetric capacity, engine capacity, commodity loading positions and pen layout.

A number of different feed delivery systems are represented within the seven feedlots. This includes stationary mixing, bunker system, batch-boxes and a number of varying combinations in mobile equipment. Mobile equipment combinations included tractor/trailed mixer units, ROTO-mix trucks (various capacities and number), loaders (number, no of ingredients and bucket capacities) and screw mixer trucks.

Whilst it is appreciated that mobile equipment is selected based on a number of criteria, it would appear that one of the major drivers of feed delivery energy usage is feed-out strategy. For example, an energy saving of 5 MJ t/ration for a feedlot delivering 100,000t of ration per year, will reduce energy usage by 500000 MJ/year or approximately 12 kL in diesel usage. At 1.50c/L, (including rebate) this equates to about $18,000/year.

## 5.5 Waste management energy usage

FIGURE 51 illustrates the average waste management energy usage on a head on feed basis for the seven feedlots. Whilst standardising energy usage on a tonne of manure basis may be more appropriate, this information was not collected from each feedlot. Note that in this section, waste management energy use comprises diesel consumed by mobile plant in pen cleaning, manure stockpiling and manure spreading. Where these activities are undertaken by contractors, their fuel has been included.

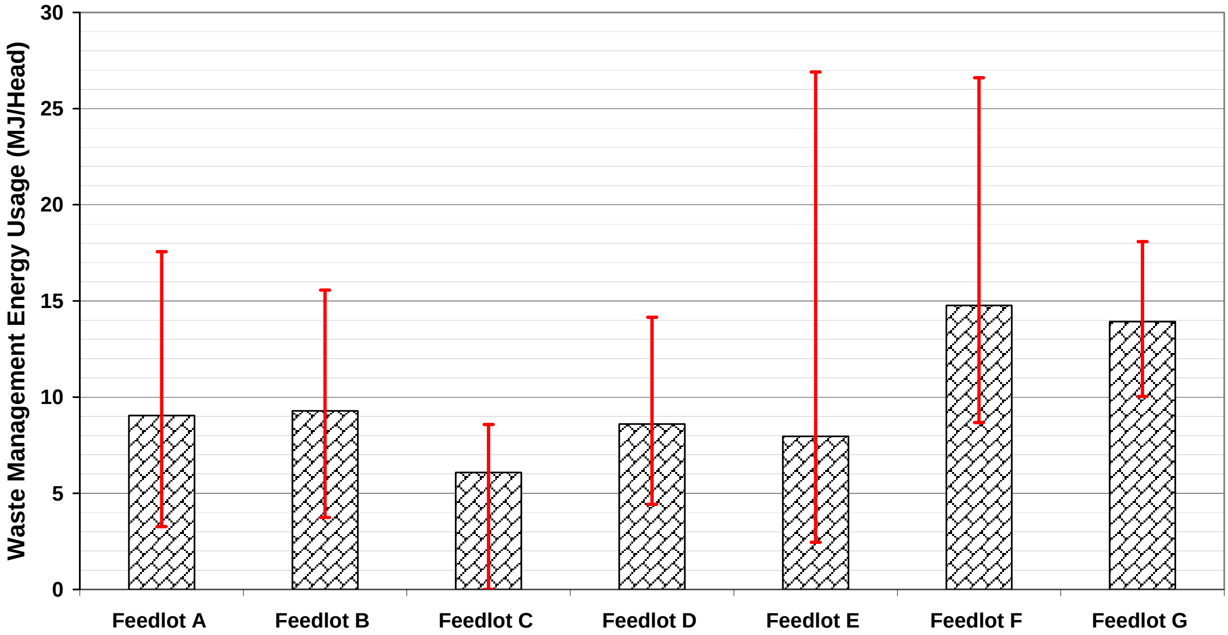



**Figure 51 – Total waste management energy usage (MJ/head on feed/month)**

The average waste management energy usage ranges from 6 to 15 MJ/head on feed/month. The variation between feedlots can be attributed to the various manure management systems employed at each feedlot. It is driven by the frequency of cleaning, equipment used and the volume of manure removed.

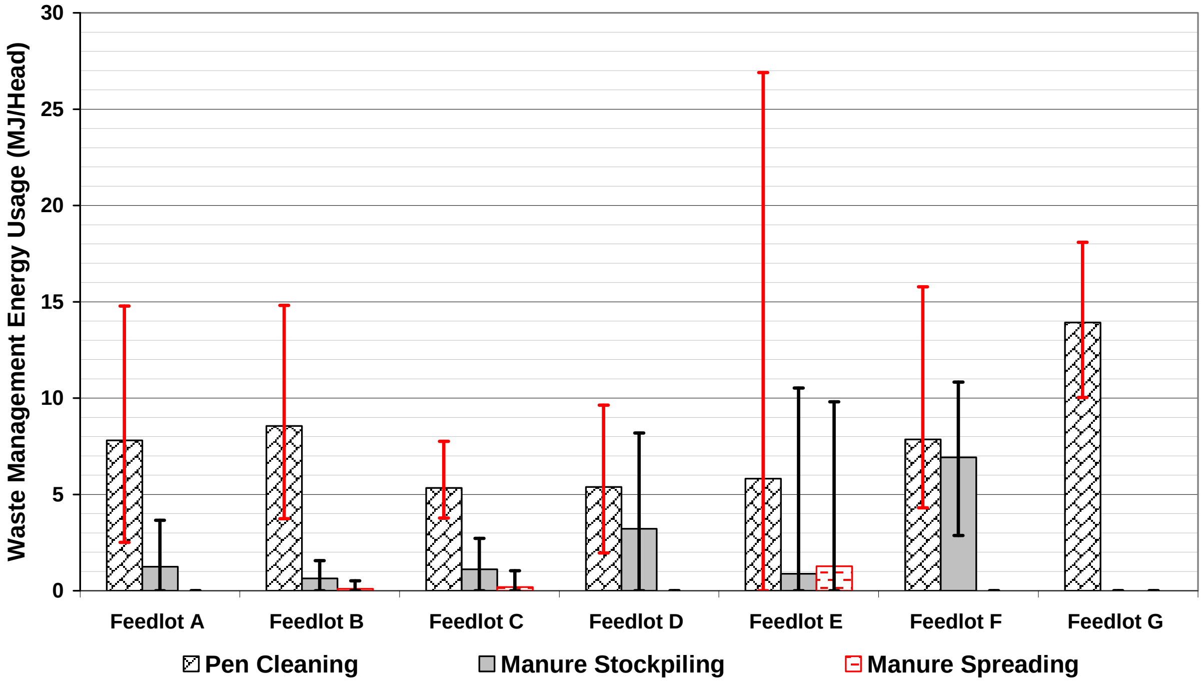



**Figure 52 – Waste management energy usage (MJ/head on feed/month)**

FIGURE 52 illustrates the average waste management component energy usage on a MJ/head on feed/month basis for the seven feedlots. Energy use for pen cleaning, manure stockpiling and manure spreading was able to be determined for all feedlots, with the exception of Feedlot G. At Feedlot G, pen cleaning energy usage also includes energy used to transporting manure to the stockpile. Where these activities are undertaken by contractors, their fuel has been included.

As expected, pen cleaning contributed the highest proportion of the total waste management energy usage. On average, pen cleaning energy usage ranged from 5 to 8.5 MJ/head on feed/month. However, usage figures up to 27 MJ/head on feed/month were measured in one month at Feedlot E. Manure stockpiling represents on average around 15% of the total energy usage. At Feedlots D and F, stockpiling is 38 and 45% respectively. Feedlots B, C and E reported manure spreading during the study period. For Feedlot E, manure spreading energy usage was slightly higher than manure stockpiling energy usage. The variation between feedlots can be attributed to the various manure management systems employed at each feedlot. It is driven by the frequency of cleaning, equipment used and the volume of manure removed.

## 5.6 Cattle washing energy usage

FIGURE 47 illustrates the average energy usage during cattle washing on a MJ per head washed basis for the seven feedlots. Feedlot C and Feedlot D do not wash cattle and that Feedlot E did not wash any cattle during the study period. The minimum and maximum water usage per head washed for any one month is presented. The feedlot numbering in this section does not match the numbering in previous sections to maintain anonymity for the participating feedlots. Whilst a summary is provided in this section, complete individual feedlot monthly cattle washing energy usage on a per head basis are presented in Appendix E.

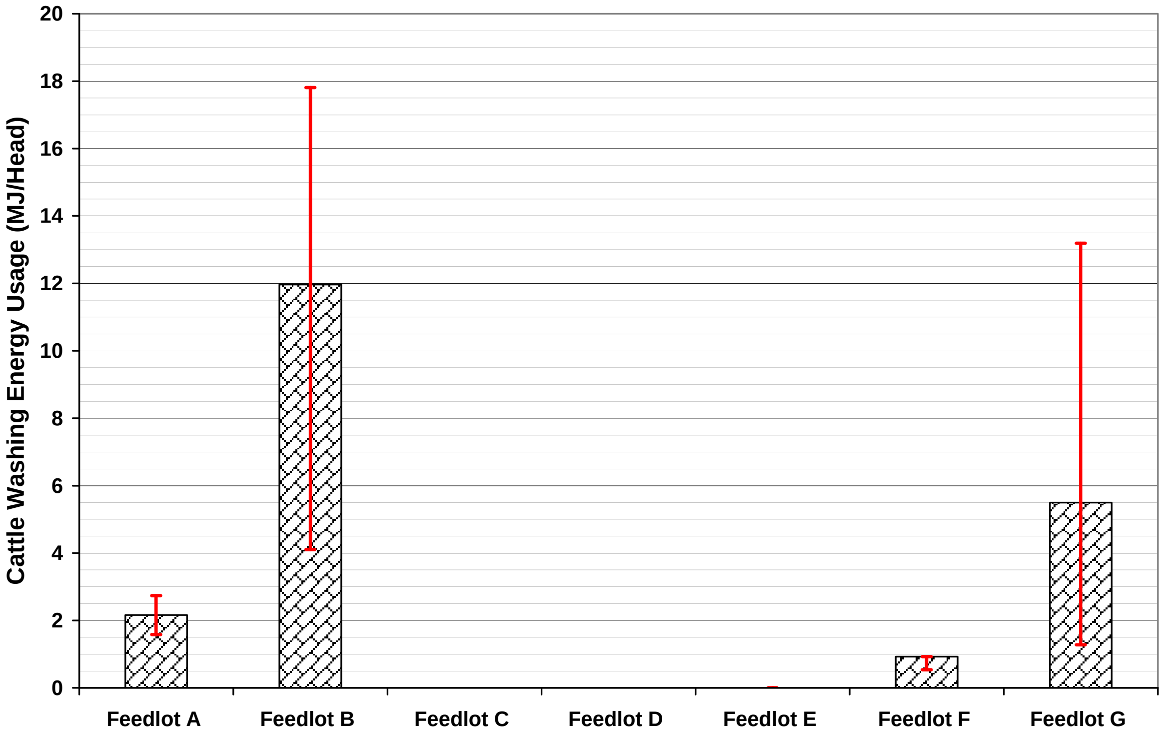



**Figure 53 – Cattle washing energy usage (MJ/head washed)**

The average cattle washing energy usage measured ranges from 1 to 12 MJ/head washed. The predominant energy source is electric but an electric and diesel powered pumping system is used at Feedlot B. The energy usage is directly proportional to the volume of water pumped and the energy source. For example, Feedlot G uses more water on average per head than Feedlot B, however energy usage is twice that used when compared with Feedlot B. This is due to one litre of diesel having a higher energy conversion than one kWh. The variability between feedlots A, F and G is directly related to respective water used in each feedlot.

## 5.7 Administration and minor activities energy usage

FIGURE 54 illustrates the average administration energy usage on a MJ per full time staff equivalent for the seven feedlots. In this context, administration energy usage is that only used by electricity in office facilities and weighbridge. The minimum and maximum administration usage per full time staff equivalent for any one month is presented. The feedlot numbering in this section does not match the numbering in previous sections to maintain anonymity for the participating feedlots. Whilst a summary is provided in this section, complete individual feedlot monthly administration energy usage on a MJ per kg HSCW gain basis are presented in Appendix E, Section E.1.

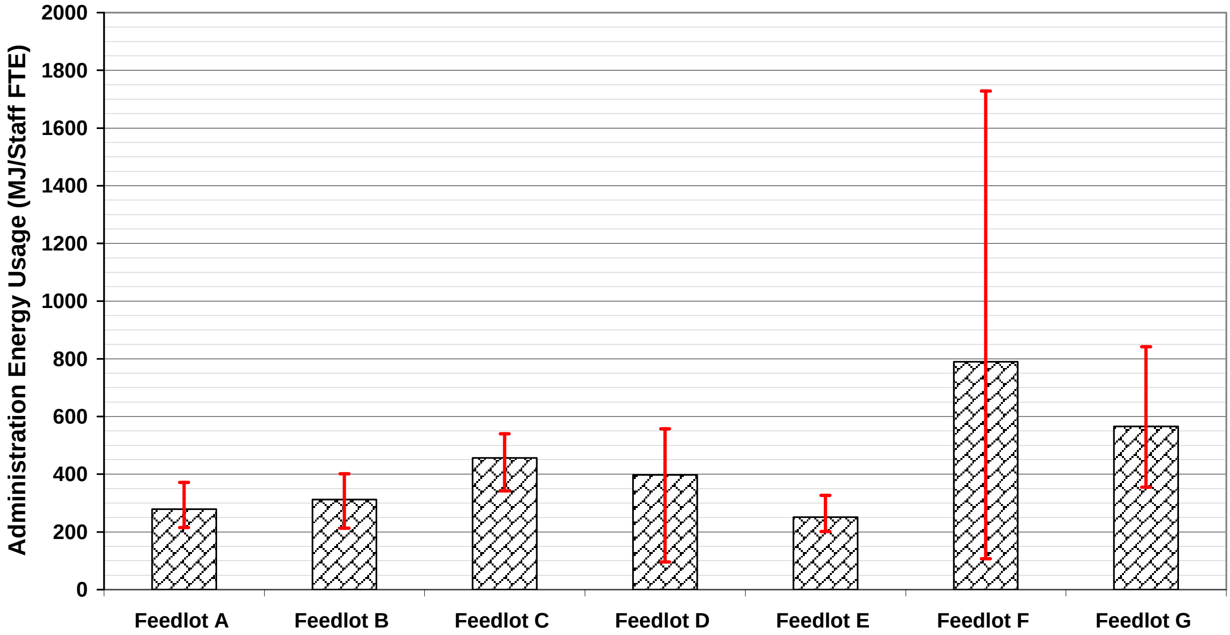



**Figure 54 – Administration energy usage (MJ/staff FTE)**

The average administration energy usage ranges from 240 MJ/staff FTE at Feedlots E to 530 MJ/ Staff FTE at Feedlot A where administration electricity usage was metered separately. For Feedlot F, electricity usage for administration purposes includes a residence, office and workshop. There is a high variation in usage at feedlots D and G with Feedlot D having ranged from 100 to 550 MJ/Staff FTE. The higher usage is associated with the warmer months suggesting that air conditioning of the office facilities is driving energy usage.

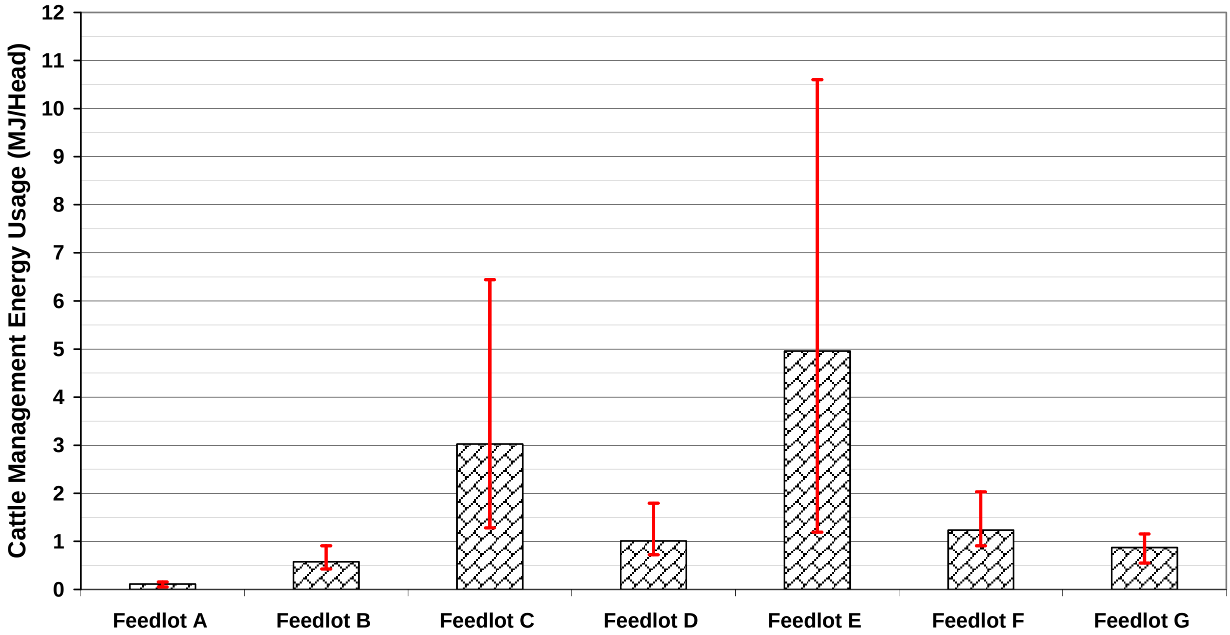



**Figure 55 – Cattle management energy usage (MJ/head processed)**

FIGURE 55 illustrates the average cattle management energy usage on a MJ per head processed basis for the seven feedlots. In this context, cattle management energy usage includes induction/hospital and is expressed per total head processed (inducted and shipped), not head on feed. Energy usage is predominantly electricity used for lighting, cleaning and restraint facilities. Note that the energy usage for Feedlot C and E was determined by residual and includes other minor uses such as fuel bowser, staff amenities and stables. The minimum and maximum cattle management usage per head basis for any one month is presented. Whilst a summary is provided in this section, complete individual feedlot monthly cattle management usage on a MJ per kg HSCW gain basis are presented in Appendix E, Section E.2.

The average energy usage for cattle management ranges from 0.10 MJ/head processed at Feedlot A to 5 MJ/head processed at Feedlot E.

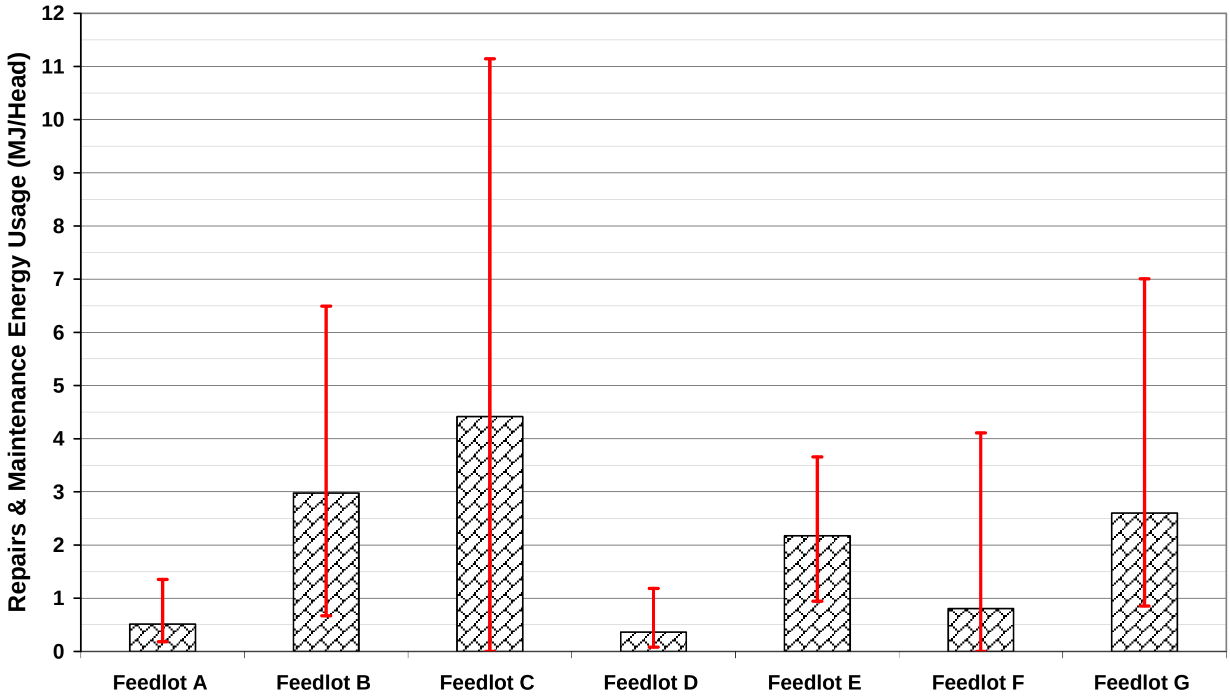



**Figure 56 – Repairs and maintenance energy usage (MJ/head on feed/month)**

FIGURE 56 illustrates the average repairs and maintenance energy usage on a MJ/head on feed/month basis for the seven feedlots. In this context, repairs and maintenance includes electricity usage in workshop facilities as well as diesel usage from mobile plant used in repair and maintenance activities. It is expressed as MJ/head on feed/month. The minimum and maximum repairs and maintenance usage per head basis for any one month is presented. Whilst a summary is provided in this section, complete individual feedlot monthly cattle management usage on a MJ per kg HSCW gain basis are presented in Appendix E, Section E.2.

The average energy usage for cattle management ranges from 0.4 MJ/head on feed/month at Feedlot D to 4.5 MJ/head on feed/month at Feedlot C. The large variation in repairs and maintenance energy usage and is due to the variation in mobile plant fuel usage between months.

# 6 Opportunities for energy use efficiency improvements

## 6.1 Improvements to total energy usage

The feedlot Industry is acutely aware of the direct costs of energy consumption and the effect of this cost on the economic sustainability of individual feedlots within the industry. Therefore, energy use efficiency within feedlots is a high priority. Furthermore, any reduction in energy usage is a reduction in greenhouse gas emissions, which will be increasingly important in the future.

This study had identified the energy usage of major activities and the variation in energy usage between feedlots. This variation is due to a number of factors including differing equipment, plant, feedlot layout and management.

Most energy efficiency projects deal with only some elements of an energy-consuming system, not the whole system. Hence, that is one reason why they fail to capture the full savings potential. For example, consider an electric motor driving a pump that circulates water around a facility. This system might include the following elements:

- electric motor (sizing and efficiency rating)
- motor controls (switching, speed or torque control)
- motor drive system (belts, gearboxes etc)
- pump
- pipe work
- demand for the water (or in many cases the heat or cooling it carries)

The efficiencies of these elements interact in complex ways. However, consider a simplistic situation where the overall efficiency of the motor is improved by 10% (by a combination of appropriate sizing and selection of a high efficiency model). Then overall energy efficiency is improved by 10%. However, if every element in the chain is improved in efficiency by 10%, then the overall level of energy use is:

0.9 x 0.9 x 0.9 x 0.9 x 0.9 x 0.9 = 0.53. That is 47% savings are achieved.

In most situations, such a system's perspective is rarely applied, because responsibilities for different elements of the system are allocated to different groups and the individual savings captured are small. Indeed, individual agents may not be aware of the potential for savings in other parts of the chain – or may prefer them not to happen. Further, if a system's approach is applied, it is possible to re-allocate capital costs from one area to another. For example, savings from downsizing motors and other components and using shorter pipes may offset the cost of installing larger diameter pipes (for reduced flow resistance) and improved controls.

Two areas have been identified in which energy or cost efficiency improvements could be targeted. These are feed processing and feed delivery.

Feed processing is an added cost to the feedstuff due to the cost of energy expended, equipment maintenance, person hours, etc. Processing is economically feasible only when the increased cost of the feedstuff is more than offset by the reduced kilograms of the feedstuff required to yield a kilogram of animal liveweight gain. Energy required for processing contributes much of the added cost.

Grain processing accounts for the majority of energy consumed during feed processing. Results from this work have shown that the energy consumed in grain preparation can account for up to 70% of the total feedlot energy consumption. Similarly, a large variation in grain-preparation energy usage has been measured across feedlots.

The most common energy source and a common element in all grain processing systems is electricity consumption. In most cases, electricity is provided by an overhead supply to a main switchboard then distributed internally throughout the feedlot. Electricity is used for a number of activities within grain processing including grain movement (in-loading, tempering, storage) and processing (rolling, hammer milling).

Processing grain at night to utilise ‘off-peak’ electricity tariffs in an attempt to reduce energy costs may be a realisable opportunity. However, there are obvious social and workplace health and safety issues to be considered. This approach to feed processing could provide significant cost and energy savings and is transferable to any feedlot within the industry.

A number of different feed delivery systems are represented within the seven feedlots. This includes stationary mixing, bunker system, batch boxes and a number of varying combinations in mobile equipment. Mobile equipment combinations included tractor/trailed mixer units, ROTO-mix trucks (various capacities and number), loaders (number, no of ingredients and bucket capacities) and screw mixer trucks.

Feed delivery energy usage is dependent on the system and equipment utilised, pen layout and feed-out method also influences the energy used. Whilst pen layout is fixed in existing facilities, mobile equipment (during replacement) and feed-out strategy could be targeted for energy efficiency improvements.

# 7 Conclusions and Recommendations

## 7.1 Conclusions

Energy is fundamental to a feedlot production system. Despite this, little work has been undertaken to evaluate energy consumption by feedlots. Energy use by feedlots was collected through several studies in North America in the 1970's and 1980's. To date, only a limited study on feedlot energy usage has been undertaken in Australia.

Energy consumption was classified into two categories, indirect and direct sources. Indirect sources arise mainly from the transport of cattle in and out of the feedlot and commodity delivery. Energy is used directly in the operation of the feedlot for the production of beef – feed processing, feed delivery, water supply, administration etc.

Little information exists on the energy usage of individual components of the feedlot system, viz. water supply, feed processing, feed delivery, cattle washing, waste management, administration, repairs and maintenance and cattle management. Factual information on indirect and direct energy usage was collected on individual feedlot sector operations from seven feedlots in Australia. These feedlots were representative of climatic zones, feed management systems, management styles and cattle markets.

Results from the seven feedlots studied showed that total annual indirect energy use ranged from 1.6-8 MJ/kg HSCW gain over the period March 2007 to February 2008. Distance travelled by trucks transporting cattle and delivering feed has a large impact on the energy consumed. Combined these represent a similar usage level to direct energy consumed within the feedlot subsystem.

Incoming cattle energy usage typically ranges from 0.1 MJ/kg HSCW gain to 2.0 MJ/kg HSCW gain, when cattle are sourced close to feedlots, however can range up to 4.5 MJ/kg HSCW gain. Outgoing cattle energy usage typically ranges from 0.5 MJ/kg HSCW gain to 0.9 MJ/kg HSCW gain, however a figure of 2.8 MJ/kg HSCW gain has been measured. The average annual commodity delivery energy usage ranged from 0.8 MJ/kg HSCW gain to 5.2 MJ/kg HSCW gain, however a figure of 5.4 MJ/kg HSCW gain has been recorded.

The indirect energy usage figures illustrate the proximity of respective feedlots to cattle, abattoirs and commodities. These figures also are influenced by the differences in average daily gain between long fed cattle and domestic cattle, number and type of commodities used in rations (high grain versus high roughage). These results also clearly show the impact of the drought (grain and available cattle supply) and high grain prices on the industry in particular during the latter half of 2007 and early 2008, where higher energy usage figures were recorded.

Results from the seven feedlots studied showed that total annual direct energy use ranged from a low 0.9 MJ/kg HSCW gain to 8.3 MJ/kg HSCW gain over the period March 2007 to February 2008. Expressed on a per head basis, total annual energy usage ranged from 444 MJ/head to 1483MJ/head. The total energy usage is primarily dependent on the type of feed processing system in use.

A wide variation was measured in water supply energy usage. On average, water supply represents in the order of 3% of the total energy usage. Expressed on a per head basis it ranged from

0.04 MJ/head on feed/month to 6.6 MJ/head on feed/month, with an average in the order of 2.5 MJ/head on feed/month.

Water supply energy usage between feedlots is dependent on a number of factors, including depth to groundwater and distance to supply. Within feedlots, water supply energy usage is directly proportional to the water pumped per month. Feedlot A had the highest average water supply energy consumption due to sourcing its water from bores located some distance to the feedlot and pumping against high head. Feedlots A, B, C and F have gravity fed water reticulation systems. Feedlot D, demonstrates the additional energy usage with having to deliver water to the pens via a pumping system compared with a gravity supply system. In this case, energy consumed in delivering water to the pens is greater than supplying water to storage facilities.

Feed management is the largest single consumer of energy in the feedlot as expected. For those feedlots with steam flaking systems it contributed on average approximately 80 % of total usage, whilst those feedlots which process their grain by other means it represents around 45% of total energy usage.

Feed management energy usage has been proportioned into feed processing and feed delivery usage. Feed processing energy usage on a tonne of grain processed basis ranged from 20 to 365 MJ/t grain processed. Three different feed processing systems are represented within the seven feedlots. For feed processing systems other than steam flaking, average energy usage is typically less than 50 MJ/t grain processed. For steam flaking, the total energy usage ranges from 280 to 365 MJ/t grain processed. Hence, there is a large variation between feed processing systems and between feedlots with the same system.

The average feed processing electricity energy usage measured ranges from 20 to 50 MJ/t grain processed. The variation in electricity energy usage may be attributed to monthly variation in grain delivery, movement and storage and milling efficiency (tonnes per mill).

For steam flaking systems, a review of individual feedlot monthly feed processing data shows that there is an increase in energy usage during the cooler winter months. Hence, more energy is required to heat water and increased heat transfer losses. Setup and operation of feed processing systems will also influence total energy usage.

For steam flaking systems the average gas energy usage measured ranges from 240 to 315 MJ/t grain processed. There were three types of gases used within the four feedlots with steam flaking systems. These included LPG, butane and natural gas. All of these gas sources have different calorific values (heating content) and pricing structures. Some of the variation in gas usage can be attributed to heating efficiency during winter months.

Feed delivery energy was measured and comprised electricity used by stationary mixers, diesel consumed by loaders during feed loading and by feed trucks delivering ration to pens where appropriate. The average feed delivery energy usage measured ranges from 26 to 52 MJ/t ration delivered. A number of different feed delivery systems are represented within the seven feedlots. This includes stationary mixing, bunker system, batch boxes and a number of varying combinations in mobile equipment. Mobile equipment combinations included tractor/trailed mixer units, ROTO-mix trucks (various capacities and number), loaders (number, no of ingredients and bucket capacities) and screw mixer trucks.

The feedlot with the highest average feed delivery usage was double that of the lowest. Whilst feed delivery energy usage is dependent on the system and equipment utilised, pen layout and feed-out method also influences the energy used.

The total feed delivery energy usage was able to be divided into that consumed during loading of commodities and that used by the mobile equipment during delivery. The average energy usage by loaders ranges from 7 to 22 MJ/t ration delivered. The energy used by loaders is dependent on a number of factors including the size of loader, bucket capacity, number of ingredients loaded and the other feed related activities that the loader/s may need to undertake. Other feed related activities may include transporting hay/straw from storage areas to tub grinders, silage from silage pits, high moisture grain from storage areas etc.

A number of different feed delivery systems are represented within the seven feedlots. This includes stationary mixing, bunker system, batch boxes and a number of varying combinations in mobile equipment. Mobile equipment combinations included tractor/trailed mixer units, ROTO-mix trucks (various capacities and number), loaders (number, no of ingredients and bucket capacities) and screw mixer trucks.

A wide variation was measured in water supply energy usage. The average water supply energy usage ranged between 0.006 MJ/kg HSCW gain (0.2%) to 0.28 MJ/kg HSCW gain (13%). On average, water supply represents in the order of 3% of the total energy usage. Expressed on a per head per day basis it ranged from 0.02 MJ/head on feed/day at Feedlot G to 0.22 MJ/head on feed/day at Feedlot A, with an average in the order of 0.1 MJ/head on feed/day.

Typically, waste management contributes 18 % of total energy usage. Water supply contributed an average of 0.18 L/kg HSCW gain or around 12 % of total usage. Waste management energy usage contributed between 0.12 MJ/kg HSCW gain and 1.26 MJ/kg HSCW gain of total energy usage. Typically, it represents on average in the order of 15% of the total annual energy usage, however is quite variable between months.

Expressed on a per head on feed basis, the average annual waste management energy usage ranges from 6 to 15 MJ/head. As expected, pen cleaning contributed the highest proportion of the total waste management energy usage. On average, pen cleaning energy usage ranged from 5 to 8.5 MJ/head, however usage figures up to 27 MJ/head were measured in one month. Manure stockpiling represents on average around 15% of the total energy usage, however can range up to 45%. The variation between feedlots can be attributed to the various manure management systems employed at each feedlot. It is driven by the frequency of cleaning, equipment used and the volume of manure removed.

Cattle washing energy usage ranged between an average 0.02 MJ/kg HSCW gain (0.3 %) and 0.1 MJ/kg HSCW gain (1 %) of total energy usage. The energy consumed in cattle washing is directly related to the volume of water used. The average cattle washing energy usage on a per head washed basis ranged from 1 to 12 MJ/head washed. The predominant energy source is electric, however an electric and diesel powered pumping system are used. The variability between feedlots is directly related to respective water used for washing cattle at each feedlot.

Administration and minor activities (cattle management, repairs and maintenance) contributed an average 0.01 MJ/kg HSCW gain and 0.58 MJ/kg HSCW gain (1 %) of total energy usage. Typically, administration and minor activities represented between 4 and 20% of the total energy usage on a per kg HSCW gain basis.

The average administration energy usage ranges from 240 MJ/kg Staff FTE to 530 MJ/kg Staff FTE. The higher usage is associated with the warmer months, hence air conditioning of the office facilities is driving energy usage in these cases.

Cattle management energy usage includes both processing and hospital activities and is expressed on per total head processed (inducted and shipped) not head on feed. Energy usage is predominantly electricity used for lighting, cleaning and restraint facilities. The average energy usage for cattle management ranges from 0.10 MJ/head processed to 5 MJ/head processed.

Repairs and maintenance includes electricity usage in workshop facilities as well as diesel usage from mobile plant used in repair and maintenance activities. It is expressed as head on feed. The average energy usage for cattle management ranges from 0.4 MJ/head on feed/month to 4.5 MJ/head on feed/month. The large variation in repairs and maintenance energy usage and is due to the variation in mobile plant fuel usage between months.

Actual energy usage levels within individual activities have been recorded in seven feedlots representative of the Australian Feedlot Industry. These included water supply, feed management, waste management, cattle washing and administration and minor activities (cattle management and repairs and maintenance).

The outcomes of this study will allow the feedlot industry to develop a better understanding of the impact and relativity that various feedlot sector operations have on overall energy consumption. This information is invaluable for future design and management considerations. This study offers individual feedlot operators the opportunity to identify options for conserving energy in the feedlot and estimated cost benefits for alternative management practices if they were implemented.

Knowledge of the total energy consumption will allow the industry to benchmark itself against other intensive or extensive livestock industries and or industrial processes.

The outcomes of this study will allow the feedlot industry to start benchmarking total water usage, hence addressing the public misconceptions associated with the water used in the production of one kilogram of grained beef. In addition, this information is invaluable for participating feedlots in understanding the drivers of drinking water consumption and targeting high water use areas for efficiency gains and for future design and management considerations.

## 7.2 Recommendations

The data collected to date have indicated a large variation in energy usage between participating feedlots. This variation can be attributed to a number of factors including water supply and reticulation, feedlot design and layout, type of feed processing and delivery systems, mobile plant involved in waste management and management and operation of these activities.

Energy usage is less dependent on climatic variation when compared with water usage. However, climatic factors will directly affect waste management (pen cleaning) and indirectly on other areas such as water supply (water requirements) and cattle washing (dagginess of cattle) energy usage.

Results have also shown that energy usage in steam flaking systems increases during periods of cooler weather.

Benchmarking of this information has raised awareness of energy usage within the participating feedlots. This project has also provided industry with a set of industry statistics on energy usage over a 12-month period. A number of feedlots have installed or upgraded plant and mobile equipment during the previous study period. Hence, continuing the data collection will allow any efficiency gains resulting from changes to activities that may have been implemented. This is important both at an industry and feedyard level.

To consolidate and build on the work already undertaken it is recommended that the data collection and collation of water and energy usage within all of the existing participating feedlots continue for a further 12 months. The rationale for this option is that all of the equipment is installed and recording well, hence is a cost-effective activity. This option would require the development, implementation and use of a simplified electronic reporting system to ensure ease and consistency in reporting.

Firstly, this will allow the industry to establish a more robust baseline for energy usage. Secondly, this will allow individual feedlots to benchmark their operation and identify areas to target for improved energy or cost efficiency. Thirdly, the impact on changes to management practices to demonstrate energy efficiency gains from changes to activities will be documented.

In addition, it is important that this information is extended to industry and industry research community. Therefore, it is recommended that a series of information sheets and case studies to assist lot feeders in understanding, planning and organising, implementing and monitoring a water and energy efficiency program based on the outcomes of this work be prepared.

This would include an ‘Understanding’, ‘Benchmarking’ and ‘Case study’ series of information sheets. The ‘understanding’ series would outline the protocols on how to develop a system to measure, collate, analyse and report energy use data, assess their water consumption for benchmarking purposes and identify energy impacts and opportunities. Examples of information sheets within this series include, but not limited to – ‘Commitment - Establishing the drivers for resource management’, ‘Understanding your system – Mapping energy distribution networks’, ‘Designing a energy usage monitoring system’, ‘Measuring energy usage’, ‘Reading power meters’, ‘Defining functional units’ etc.

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# Appendix A – Cattle transport and commodity delivery energy usage

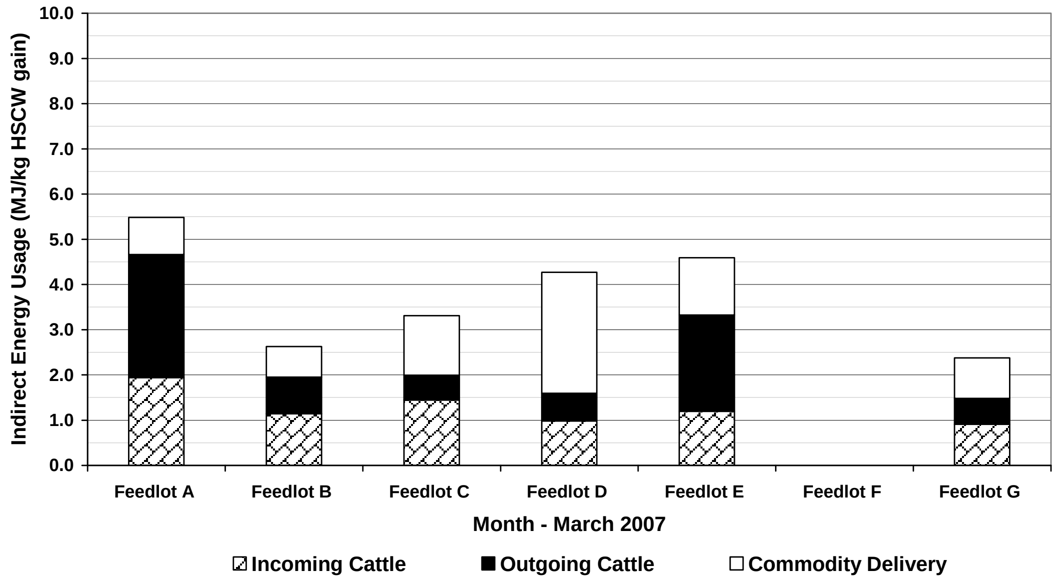


**Figure 57 – Indirect energy usage for March 2007 (MJ/kg HSCW gain)**

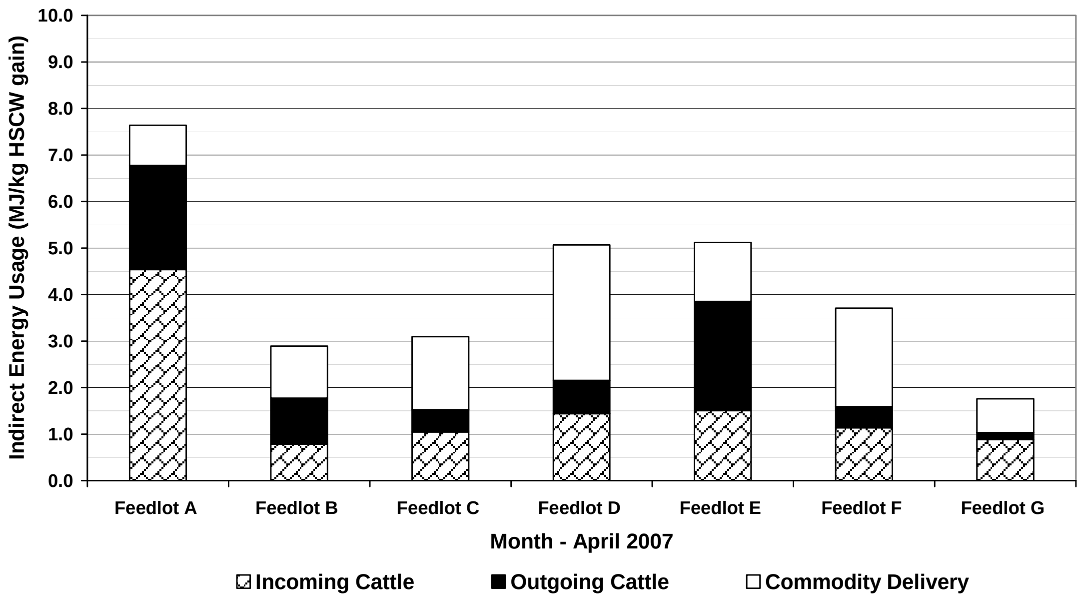


**Figure 58 – Indirect energy usage for April 2007 (MJ/kg HSCW gain)**

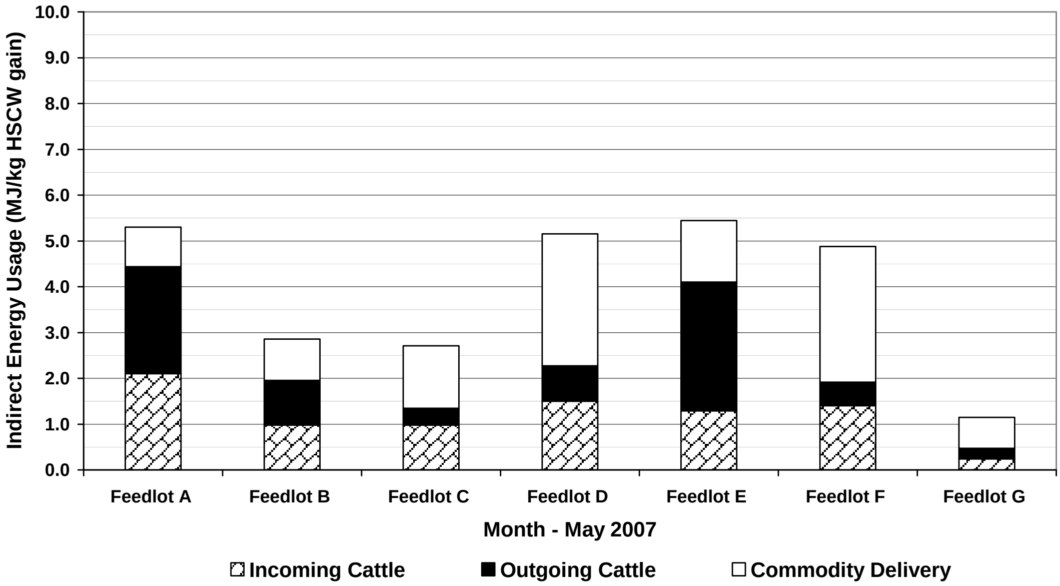


**Figure 59 – Indirect energy usage for May 2007 (MJ/kg HSCW gain)**

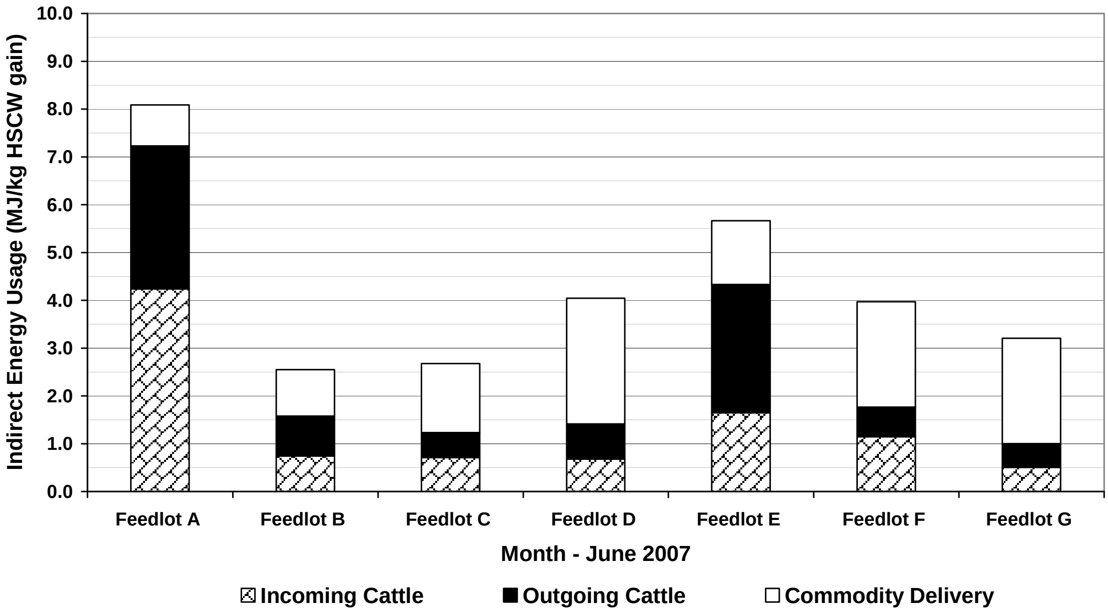


**Figure 60 – Indirect energy usage for June 2007 (MJ/kg HSCW gain)**

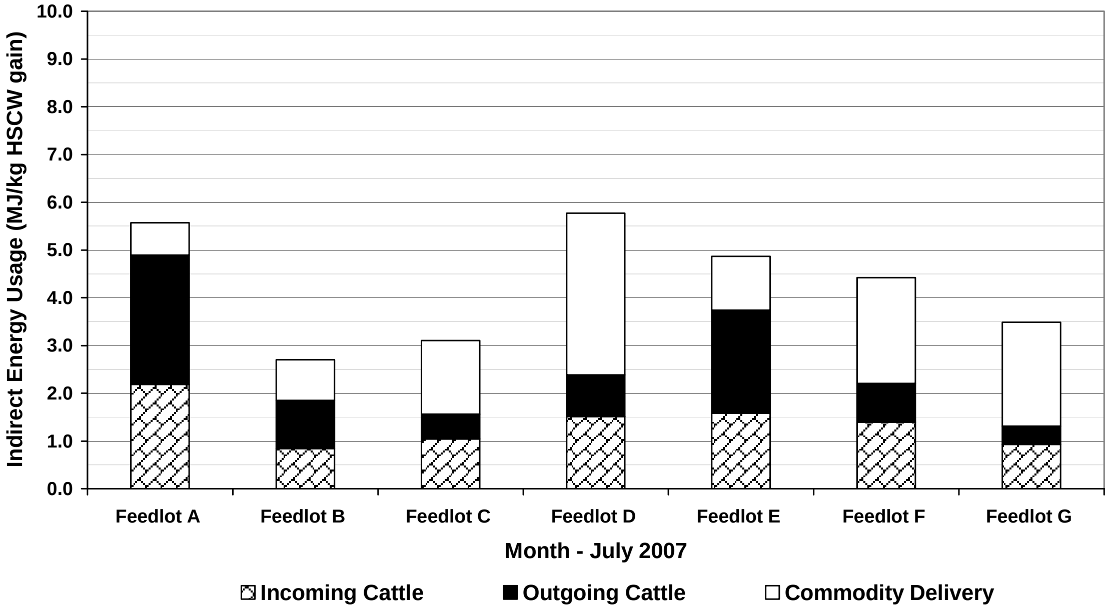


**Figure 61 – Indirect energy usage for July 2007 (MJ/kg HSCW gain)**

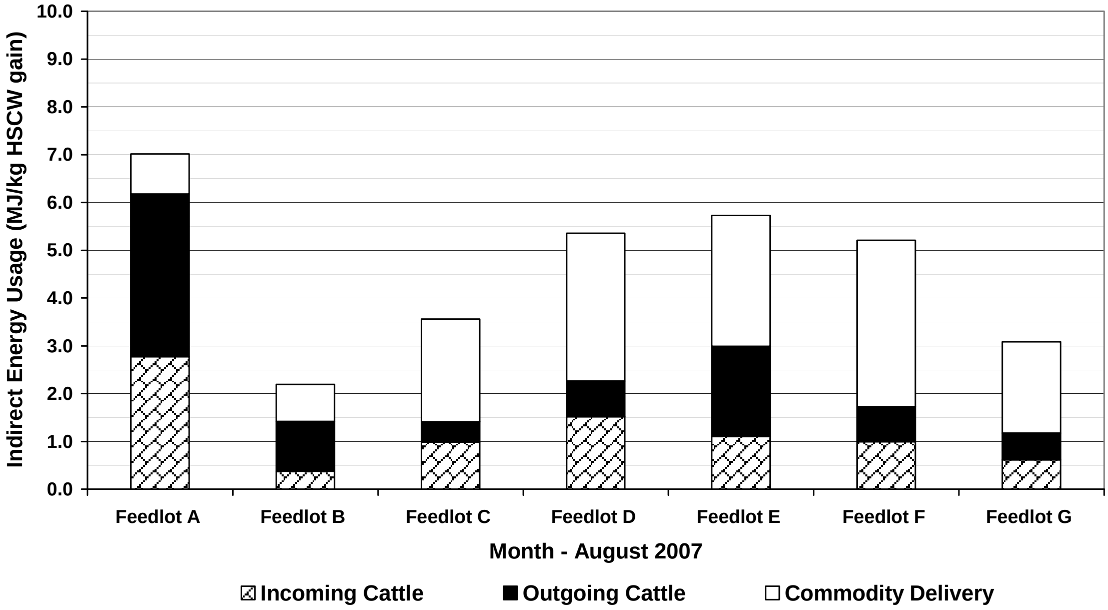


**Figure 62 – Indirect energy usage for August 2007 (MJ/kg HSCW gain)**

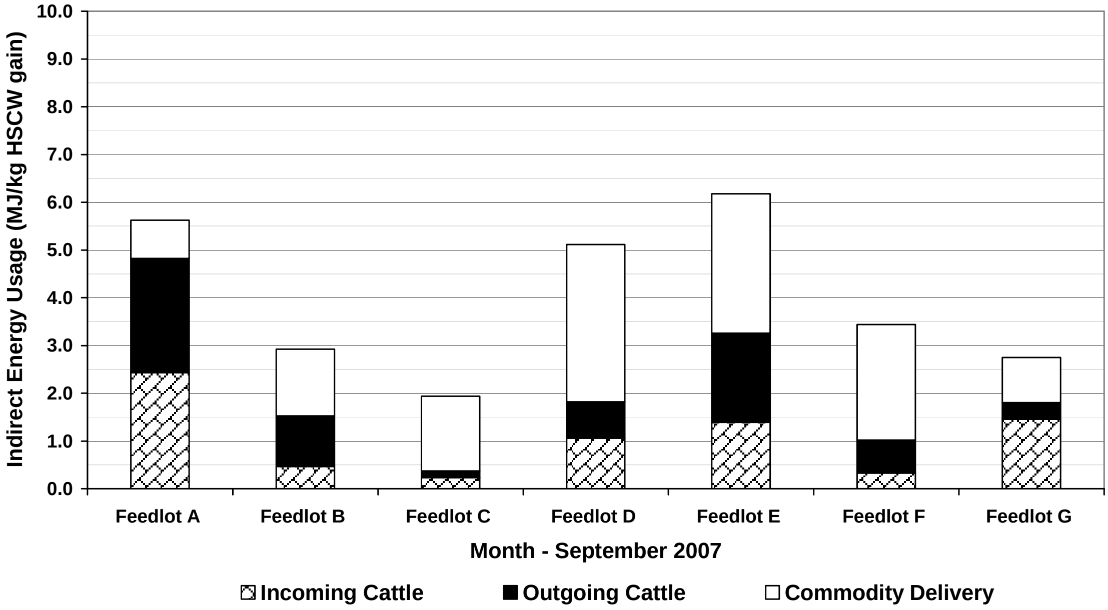


**Figure 63 – Indirect energy usage for September 2007 (MJ/kg HSCW gain)**

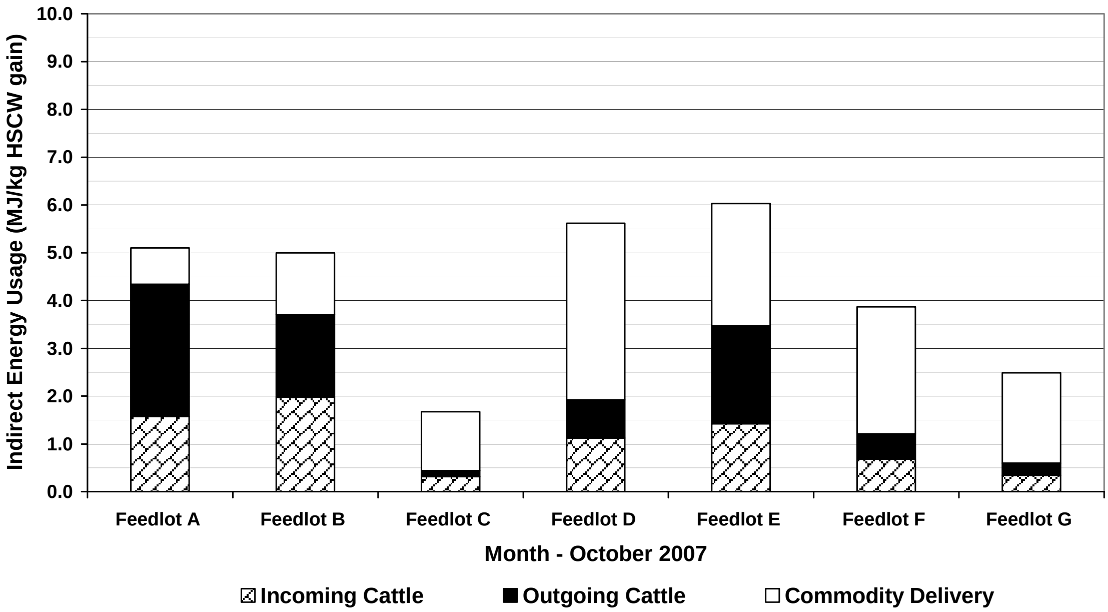


**Figure 64 – Indirect energy usage for October 2007 (MJ/kg HSCW gain)**

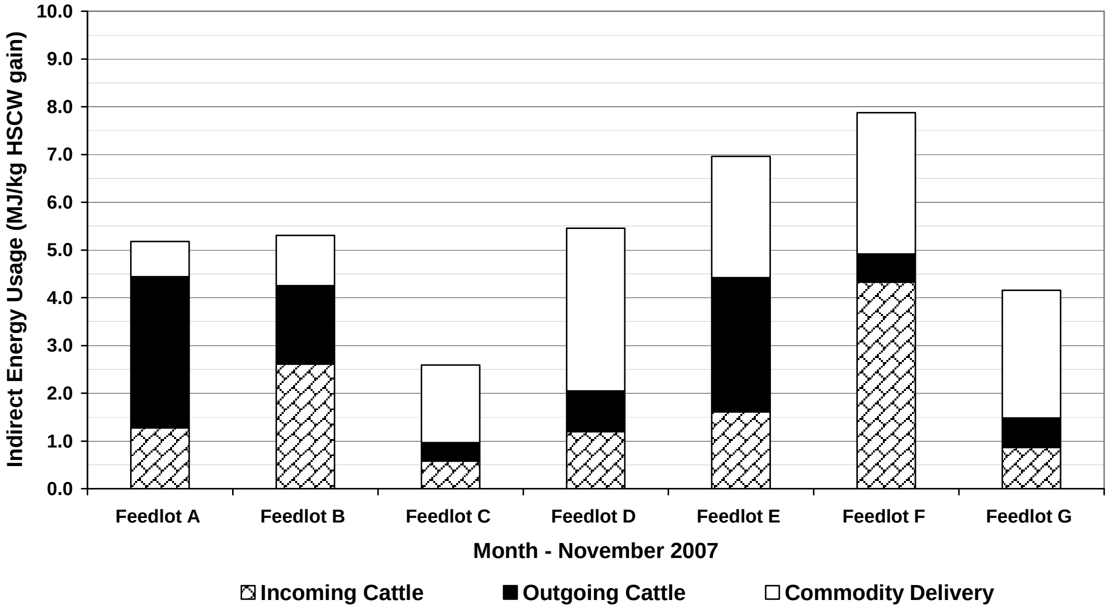


**Figure 65 – Indirect energy usage for November 2007 (MJ/kg HSCW gain)**

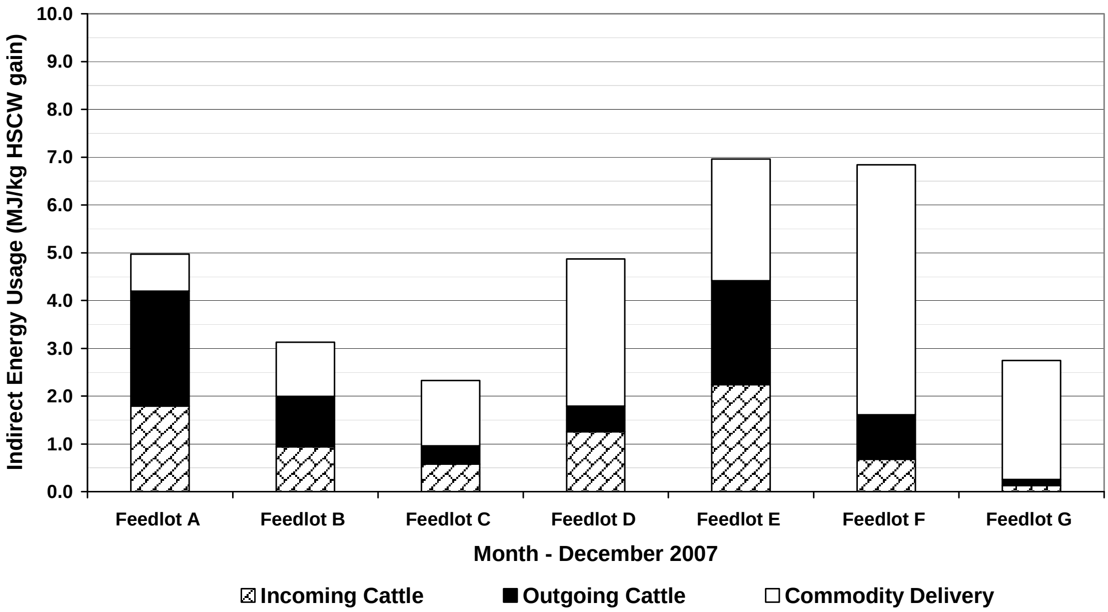


**Figure 66 – Indirect energy usage for December 2007 (MJ/kg HSCW gain)**

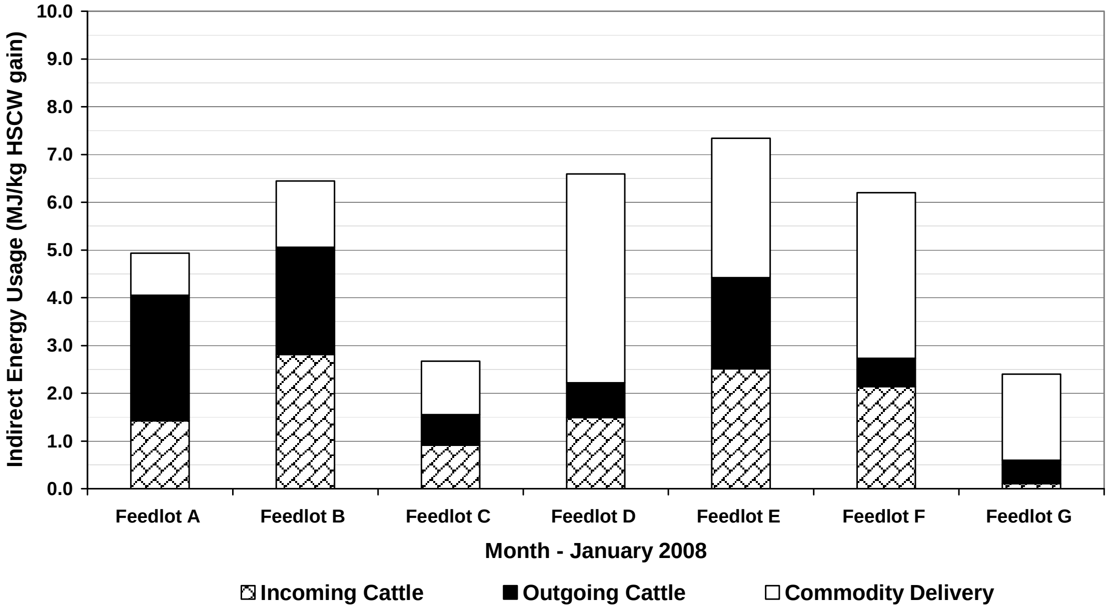


**Figure 67 – Indirect energy usage for January 2008 (MJ/kg HSCW gain)**

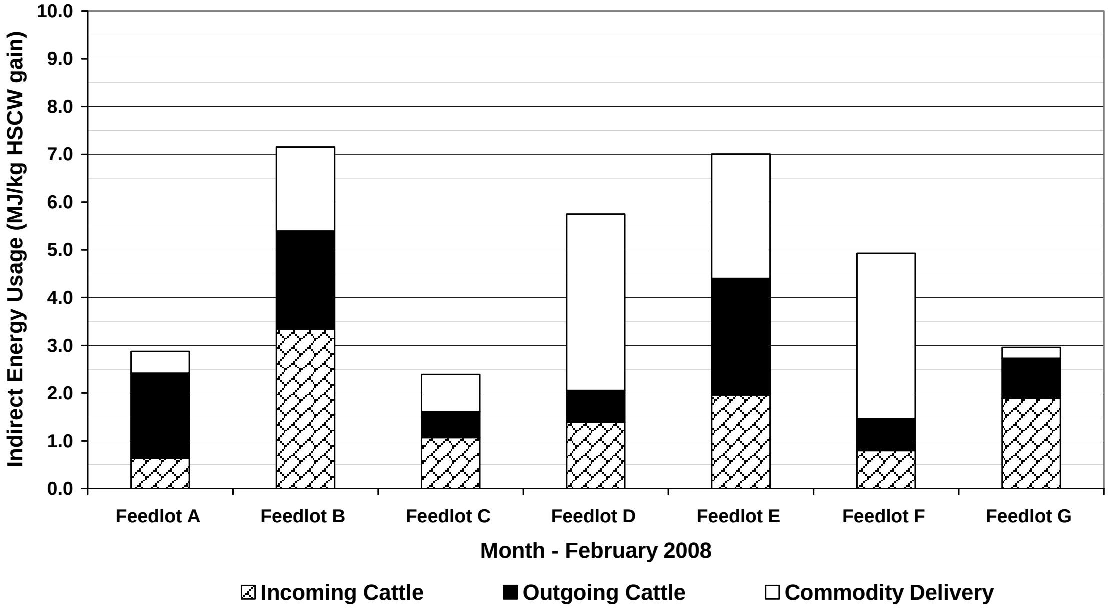


**Figure 68 – Indirect energy usage for February 2008 (MJ/kg HSCW gain)**

# Appendix B – Water supply energy usage

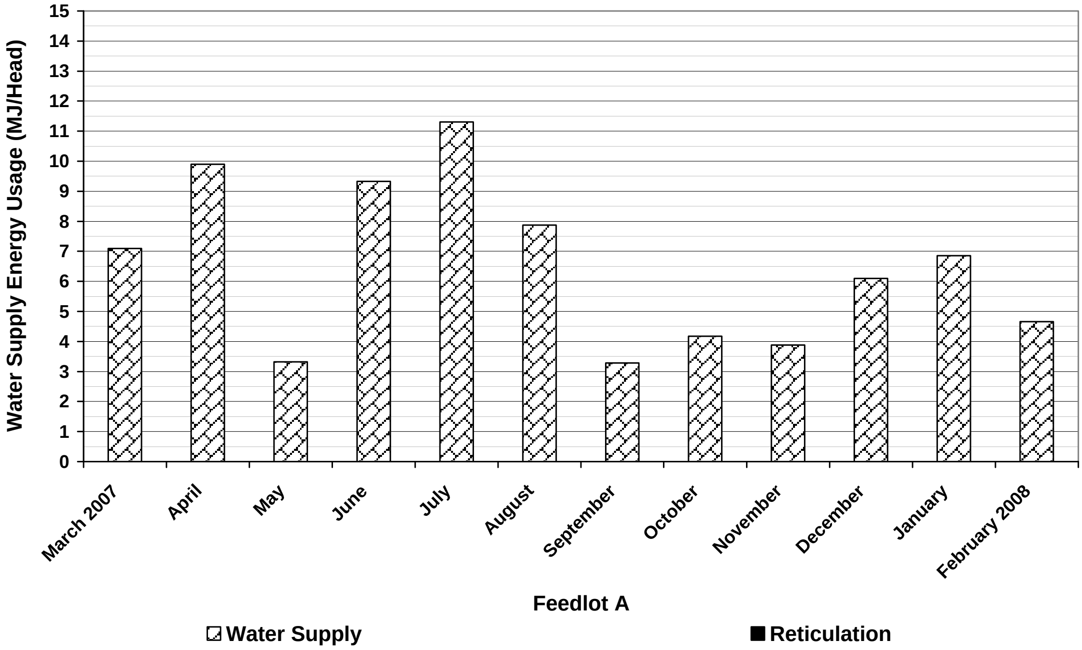


**Figure 69 – Water supply energy usage for Feedlot A (MJ/head-on-feed/month)**

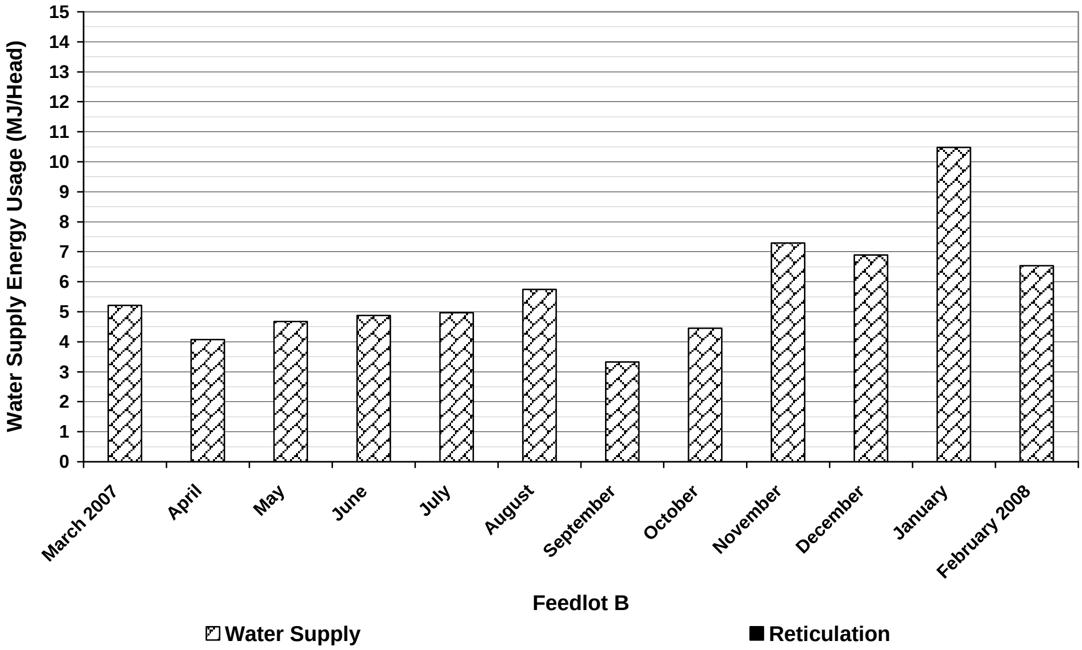


**Figure 70 – Water supply energy usage for Feedlot B (MJ/head-on-feed/month)**

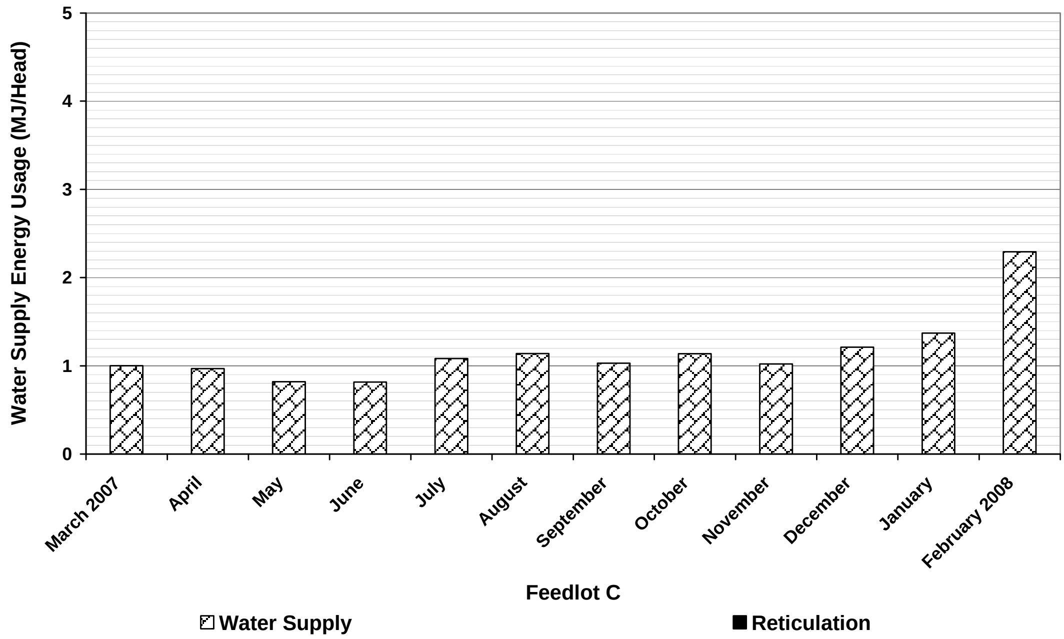


**Figure 71 – Water supply energy usage for Feedlot C (MJ/head-on-feed/month)**

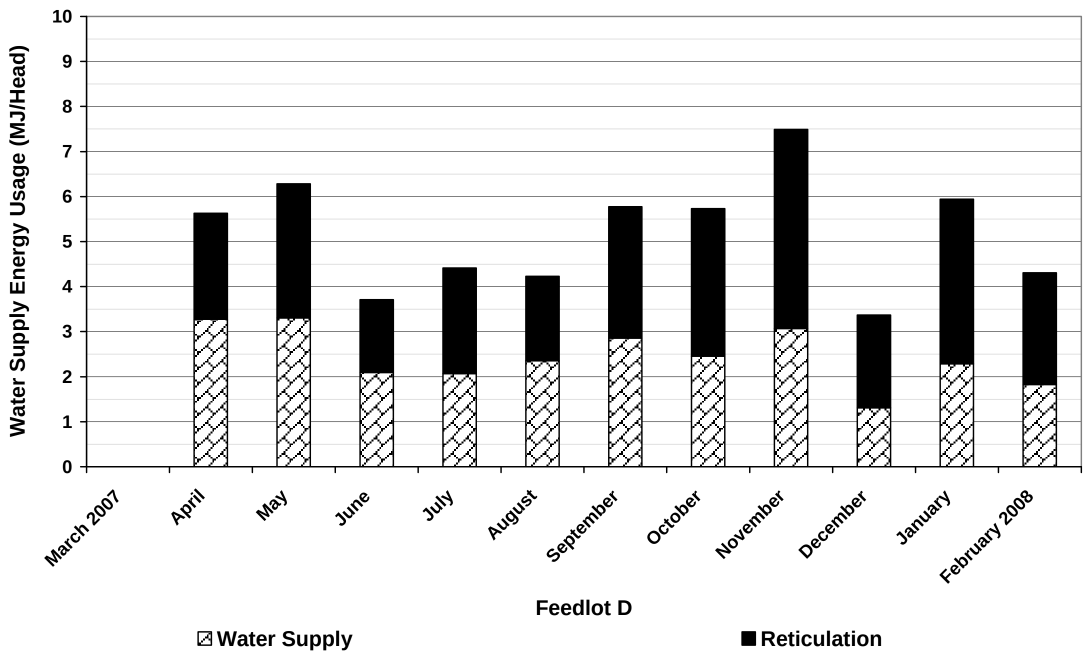


**Figure 72 – Water supply energy usage for Feedlot D (MJ/head-on-feed/month)**

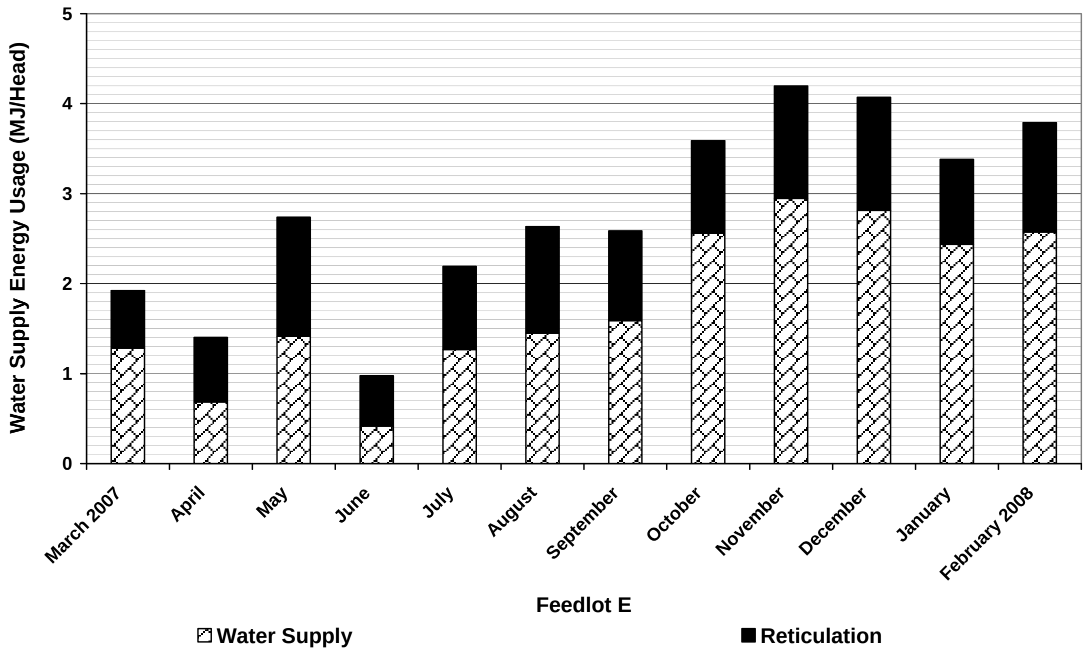


**Figure 73 – Water supply energy usage for Feedlot E (MJ/head-on-feed/month)**

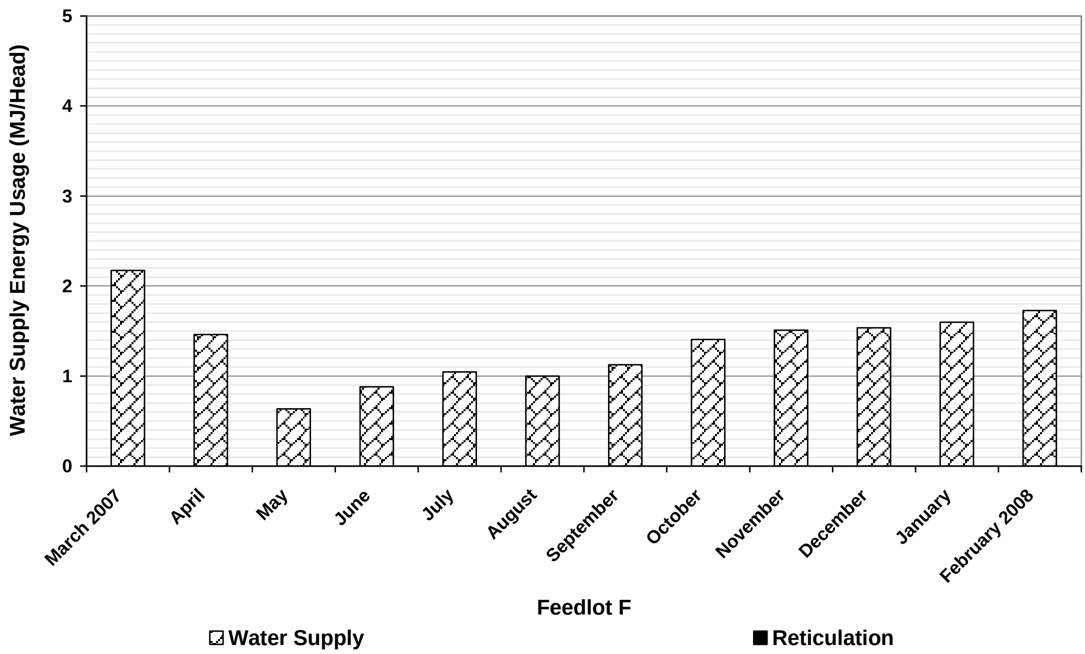


**Figure 74 – Water supply energy usage for Feedlot F (MJ/head-on-feed/month)**

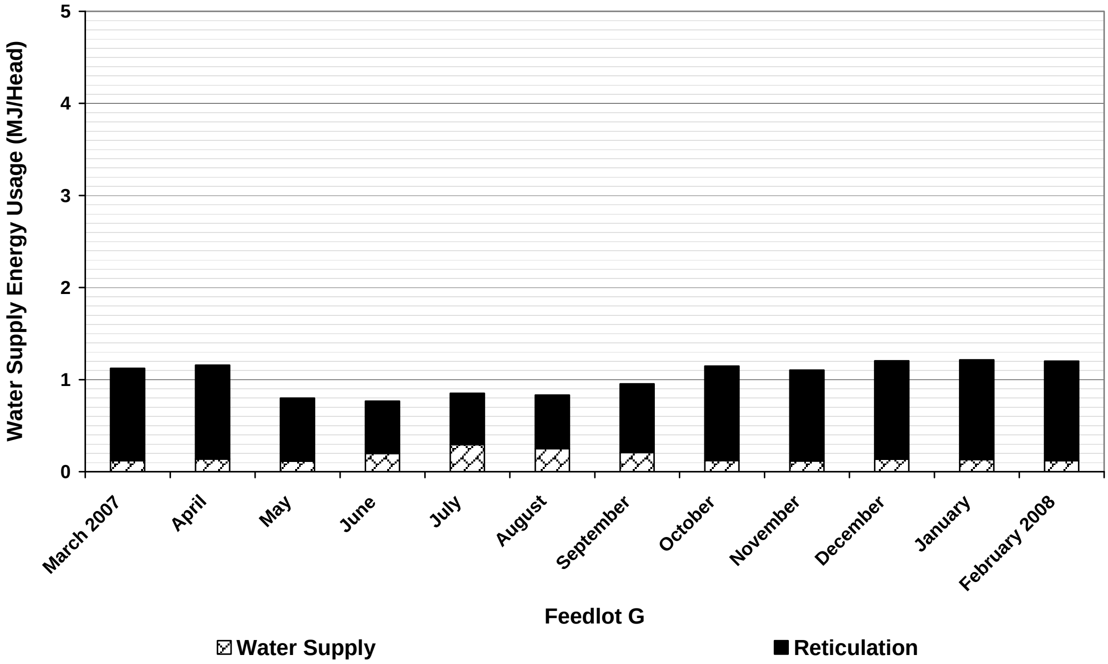


**Figure 75 – Water supply energy usage for Feedlot G (MJ/head-on-feed/month)**

# Appendix C – Feed management energy usage

## Appendix C.1 – Feed processing energy usage

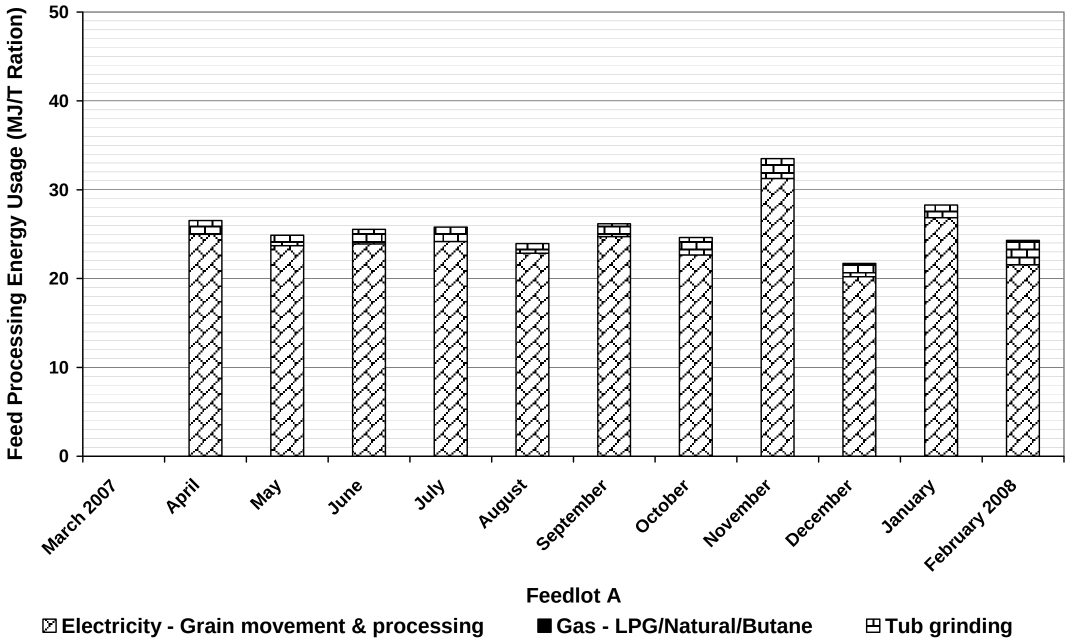


**Figure 76 – Feed processing energy consumption for Feedlot A (MJ/t ration)**

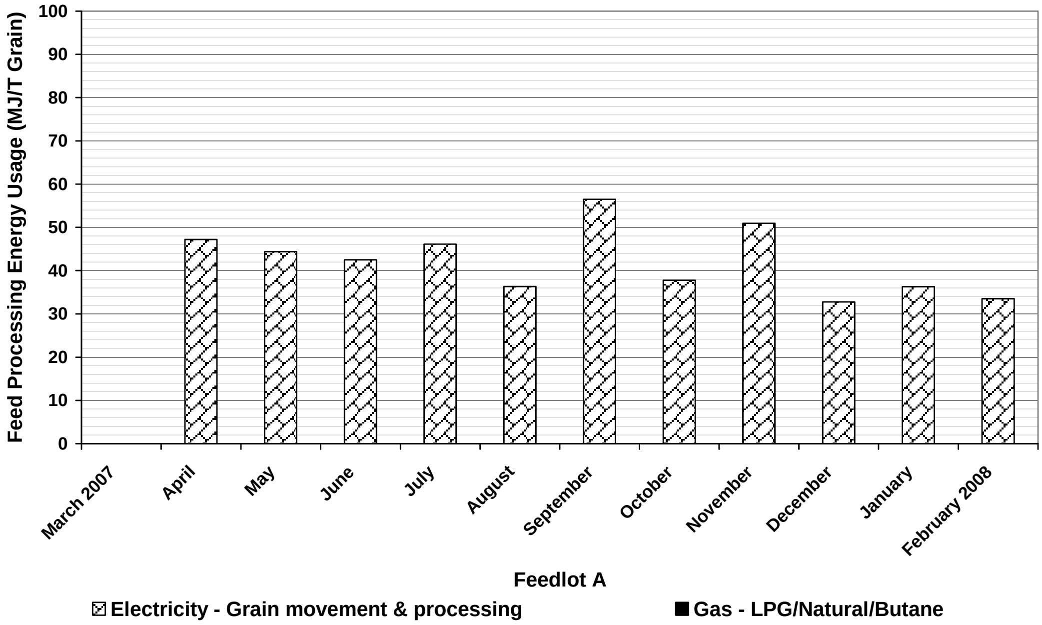


**Figure 77 – Feed processing energy consumption for Feedlot A (MJ/t grain)**

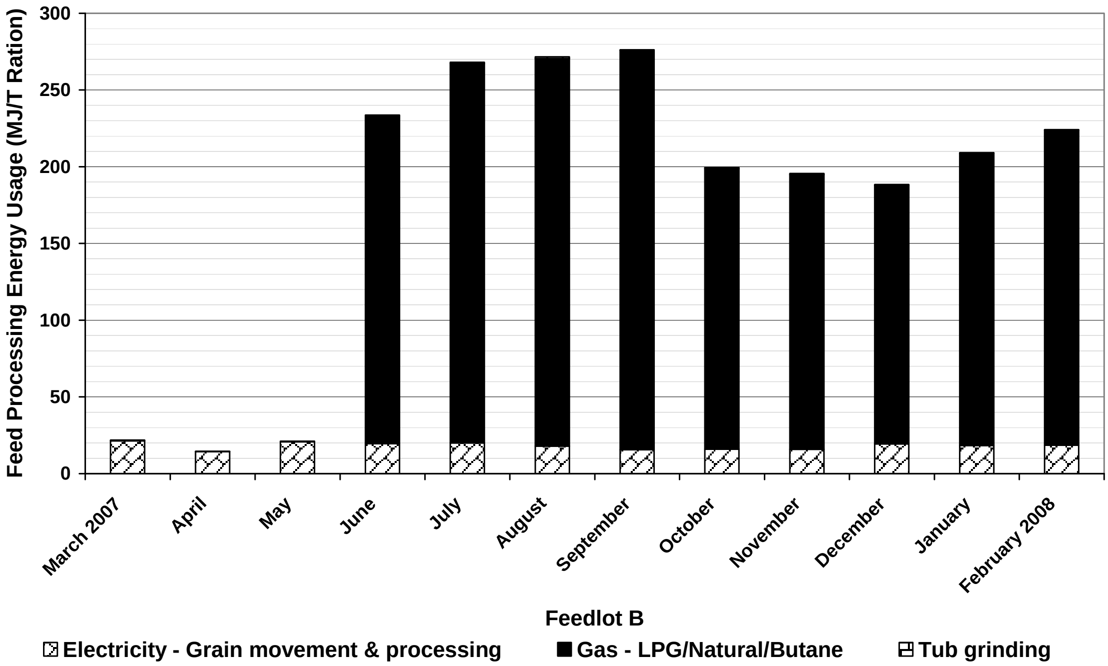


**Figure 78 – Feed processing energy consumption for Feedlot B (MJ/t ration)**

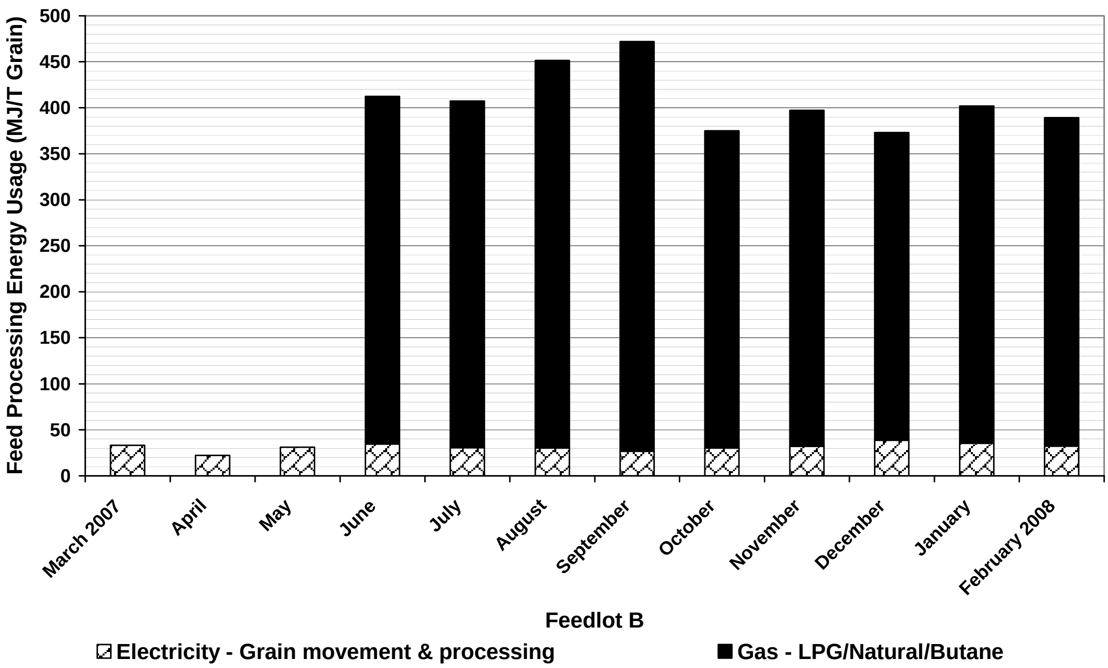


**Figure 79 – Feed processing energy consumption for Feedlot B (MJ/t grain)**

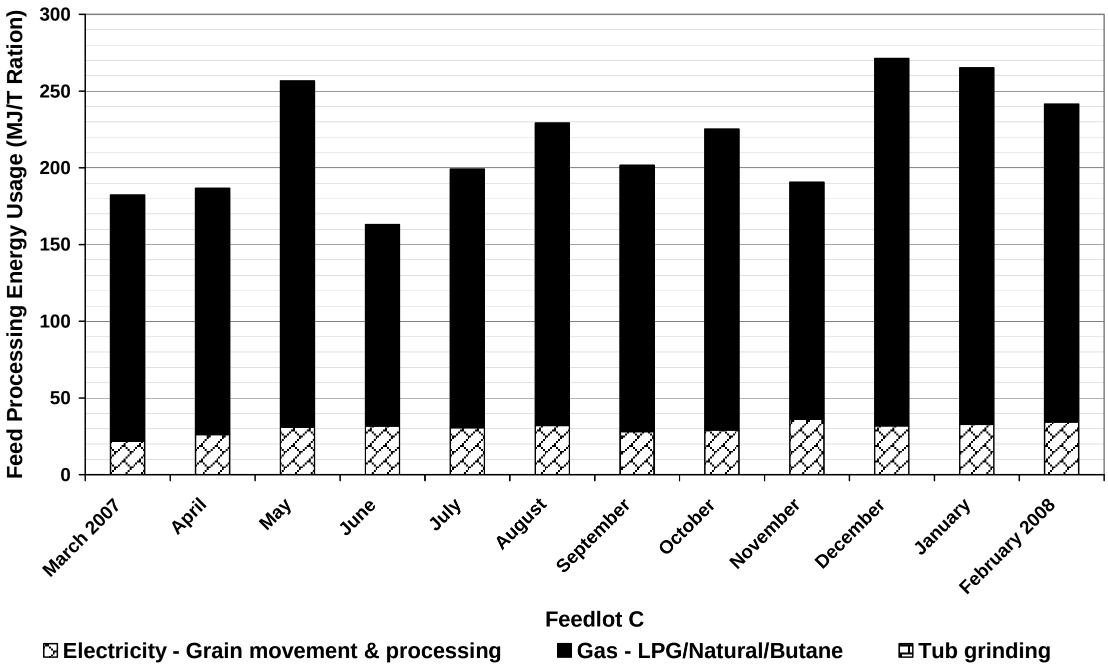


**Figure 80 – Feed processing energy consumption for Feedlot C (MJ/t ration)**

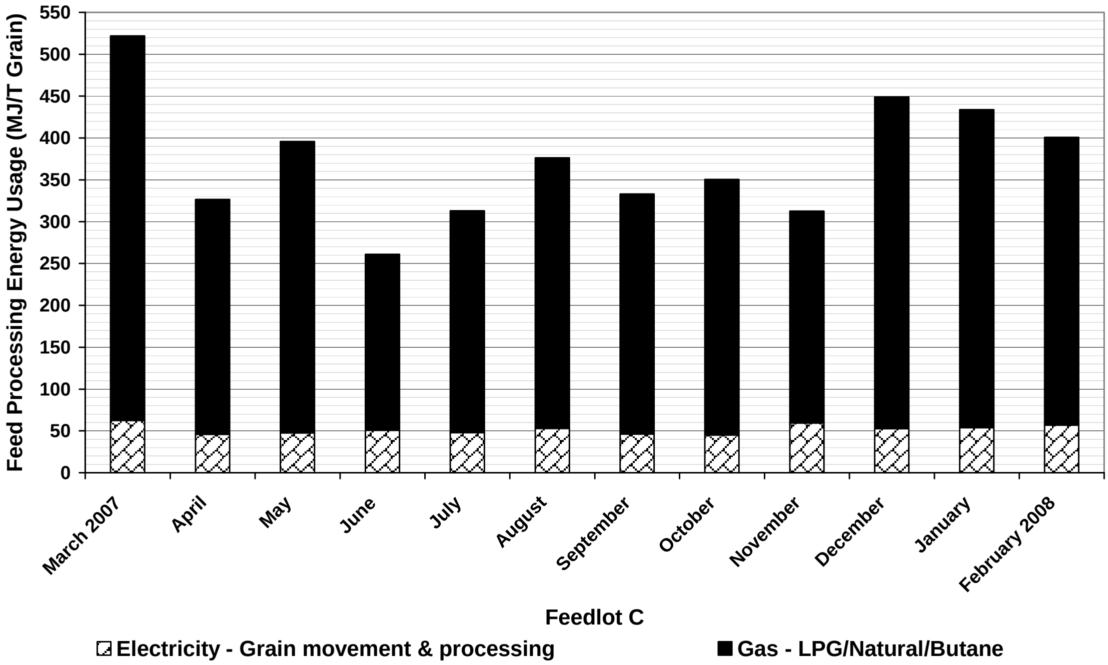


**Figure 81 – Feed processing energy consumption for Feedlot C (MJ/t grain)**

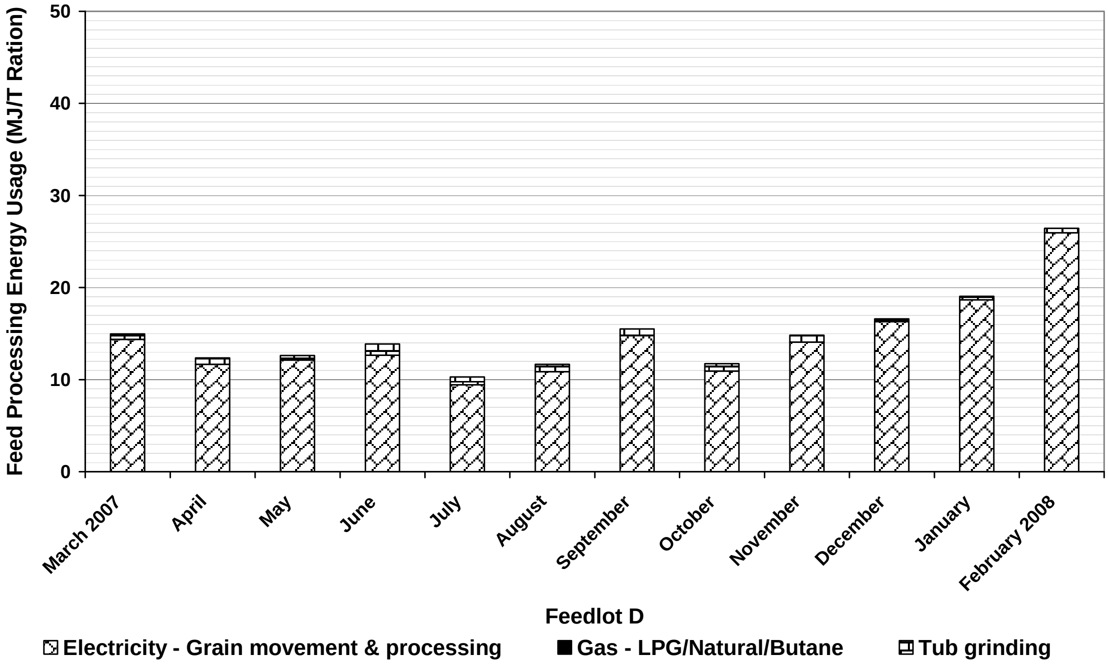


Figure 82 – Feed processing energy consumption for Feedlot D (MJ/t ration)

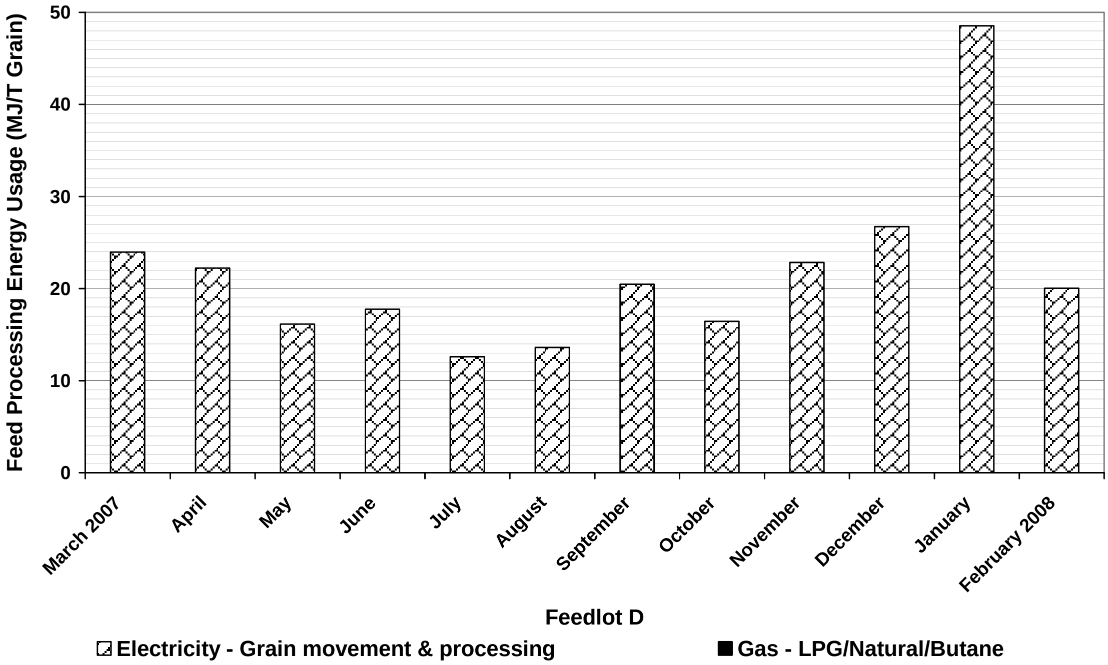


Figure 83 – Feed processing energy consumption for Feedlot D (MJ/t grain)

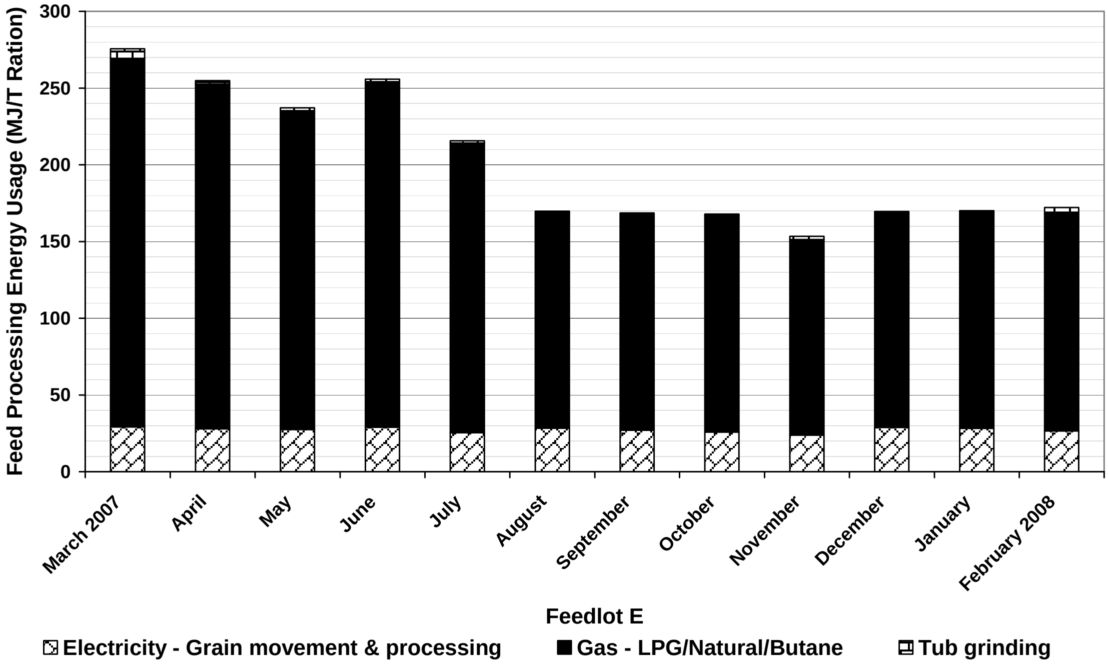


**Figure 84 – Feed processing energy consumption for Feedlot E (MJ/t ration)**

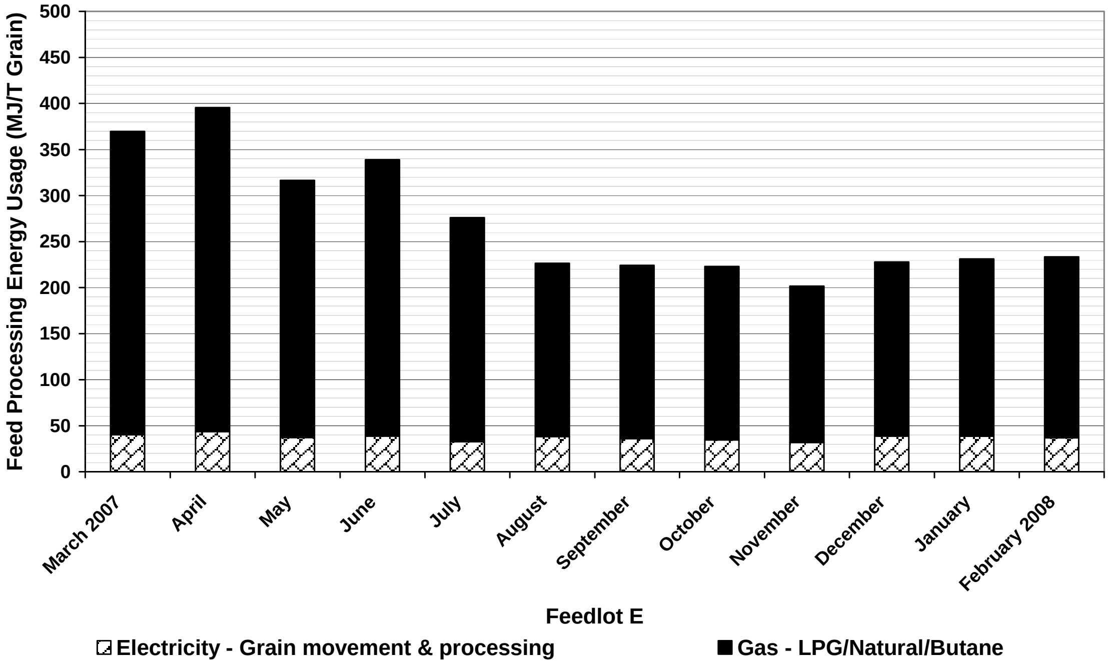


**Figure 85 – Feed processing energy consumption for Feedlot E (MJ/t grain)**

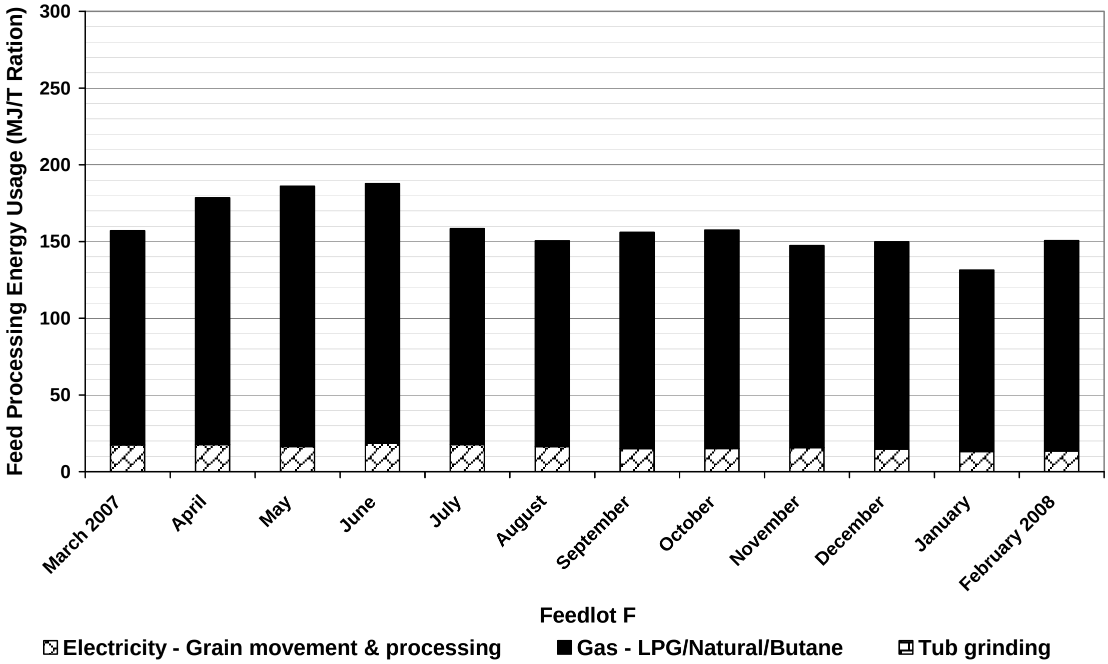


**Figure 86 – Feed processing energy consumption for Feedlot F (MJ/t ration)**

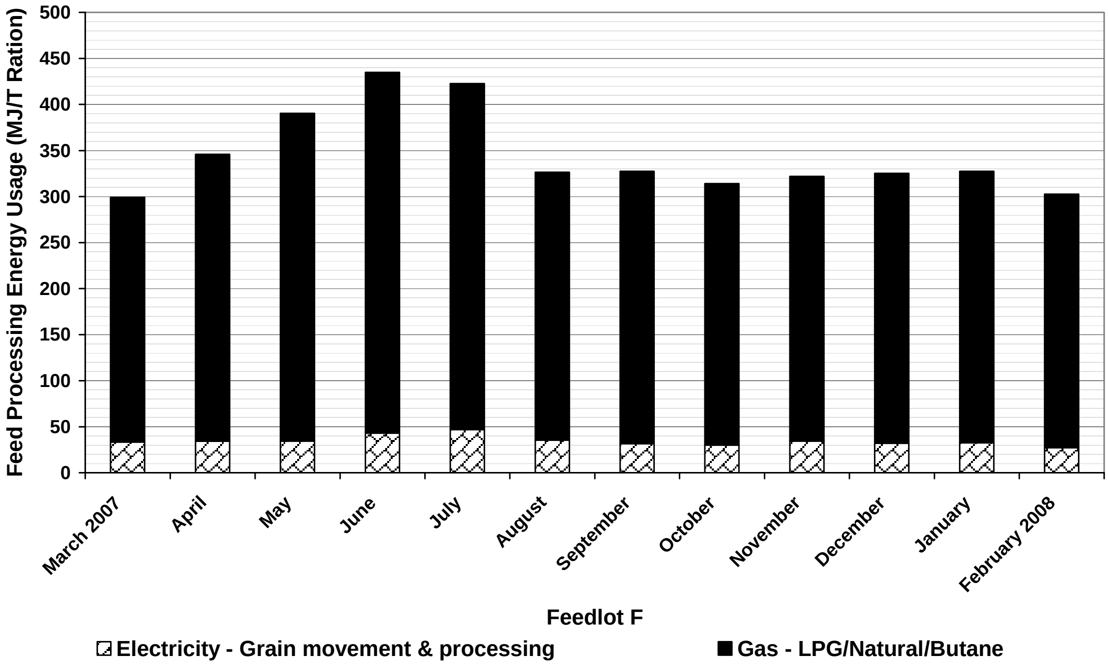


**Figure 87 – Feed processing energy consumption for Feedlot F (MJ/t grain)**

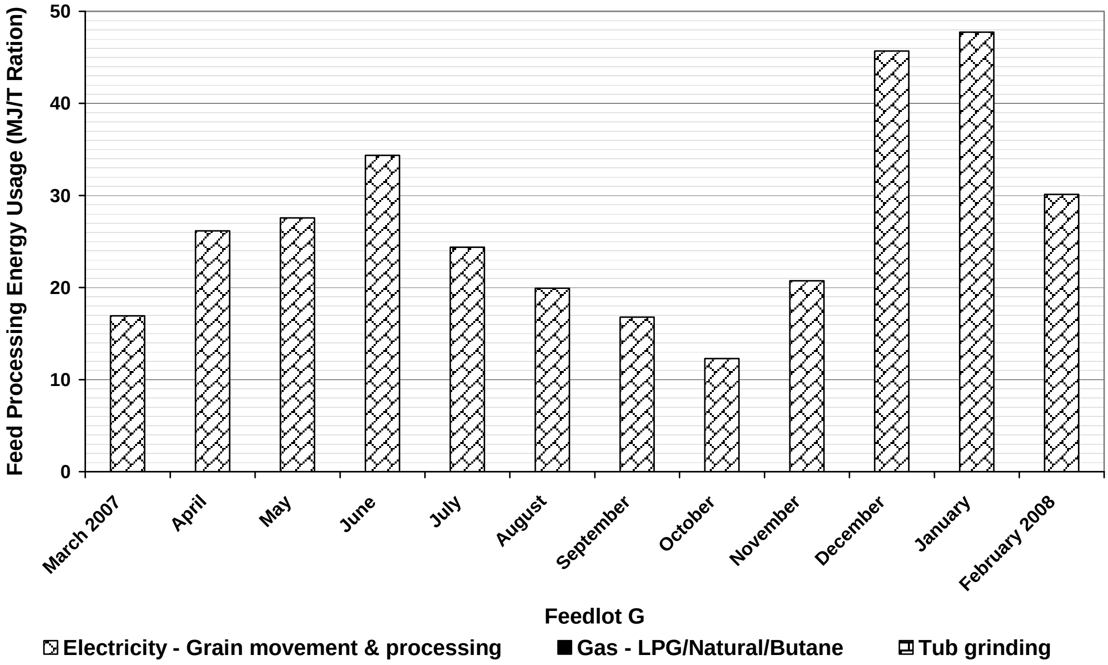


**Figure 88 – Feed processing energy consumption for Feedlot G (MJ/t ration)**

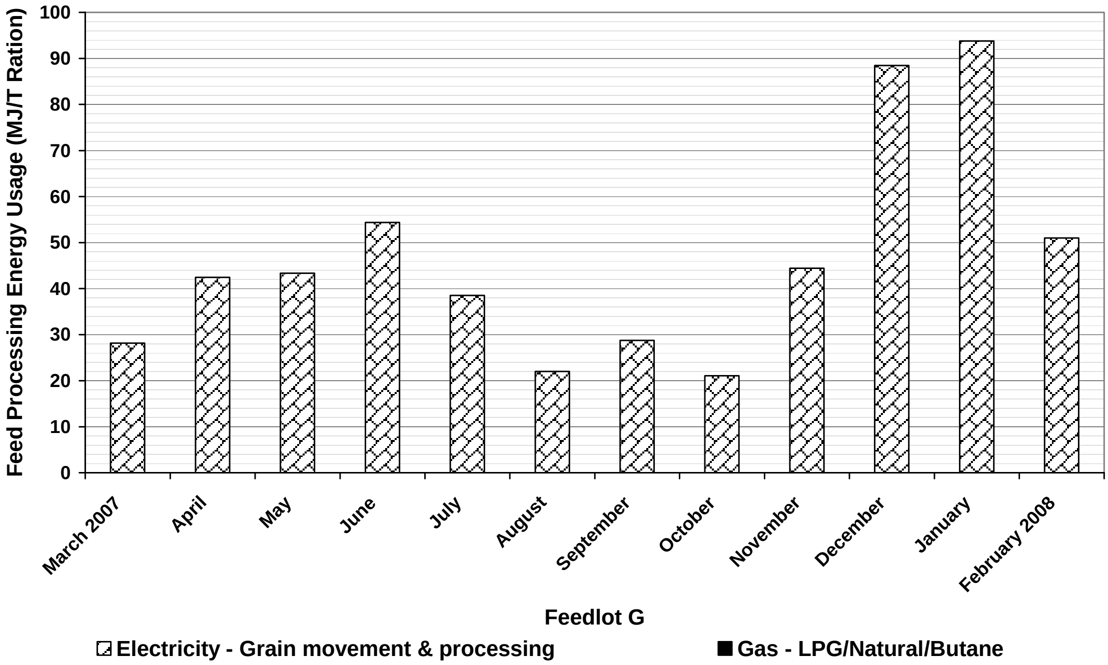


**Figure 89 – Feed processing energy consumption for Feedlot G (MJ/t grain)**

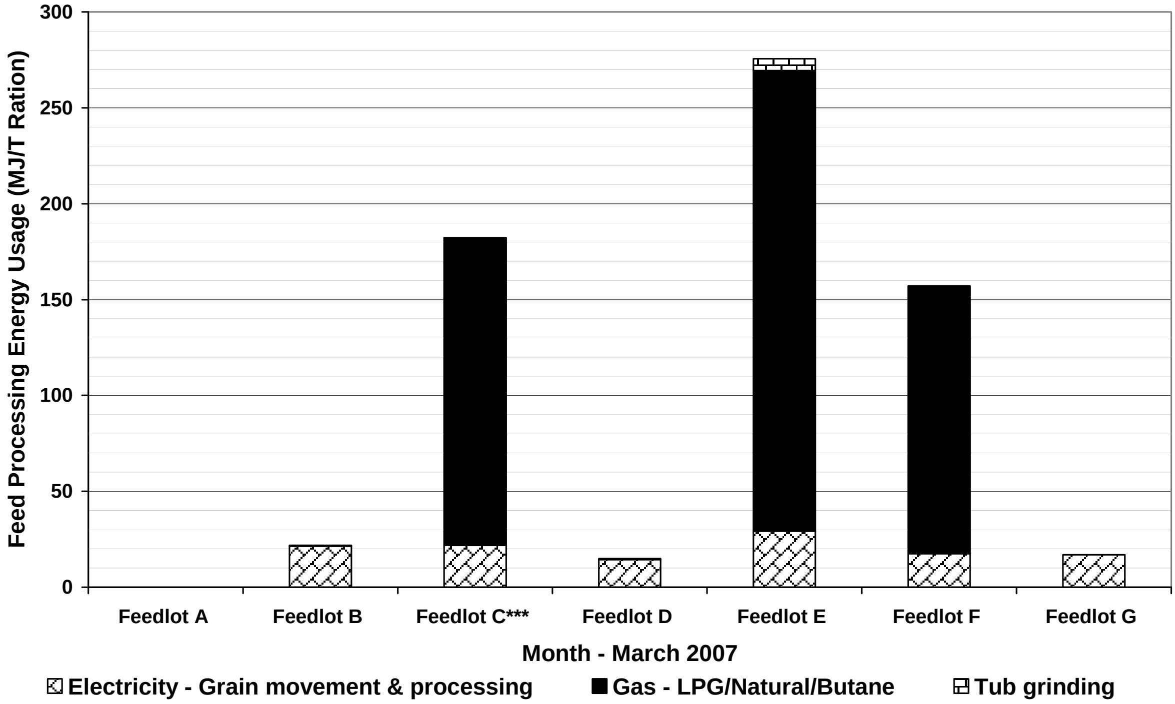


**Figure 90 – Feed processing energy consumption for March 2007 (MJ/t ration)**

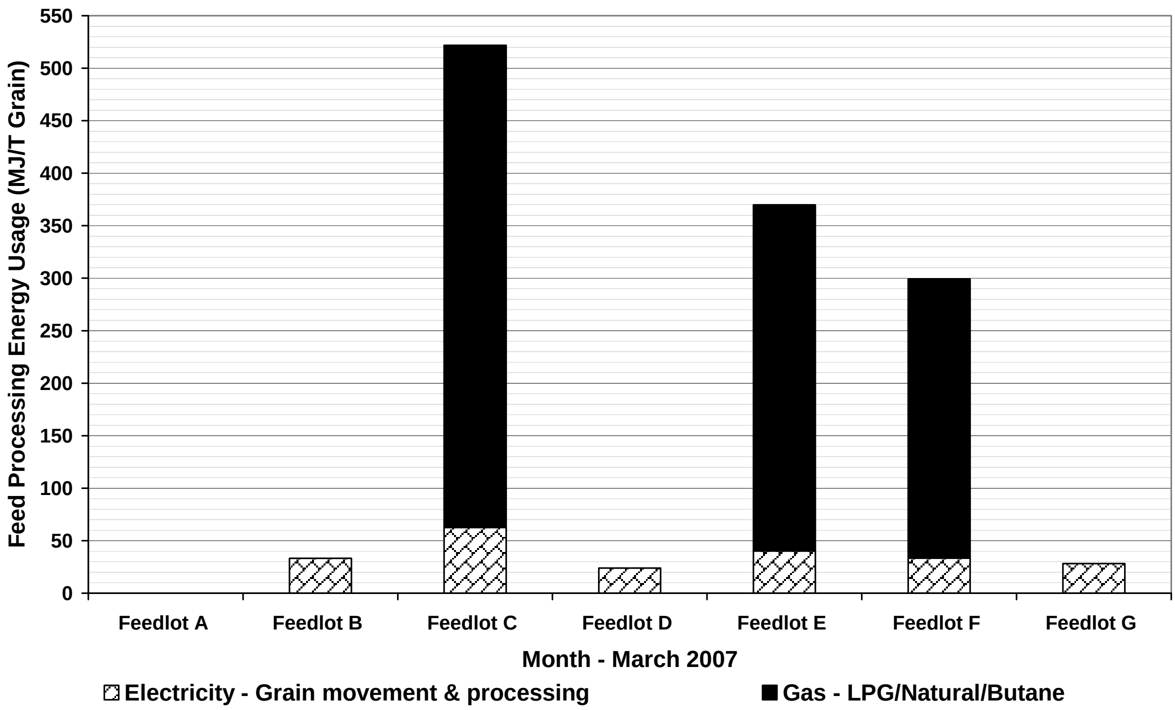


**Figure 91 – Feed processing energy consumption for March 2007 (MJ/t grain)**

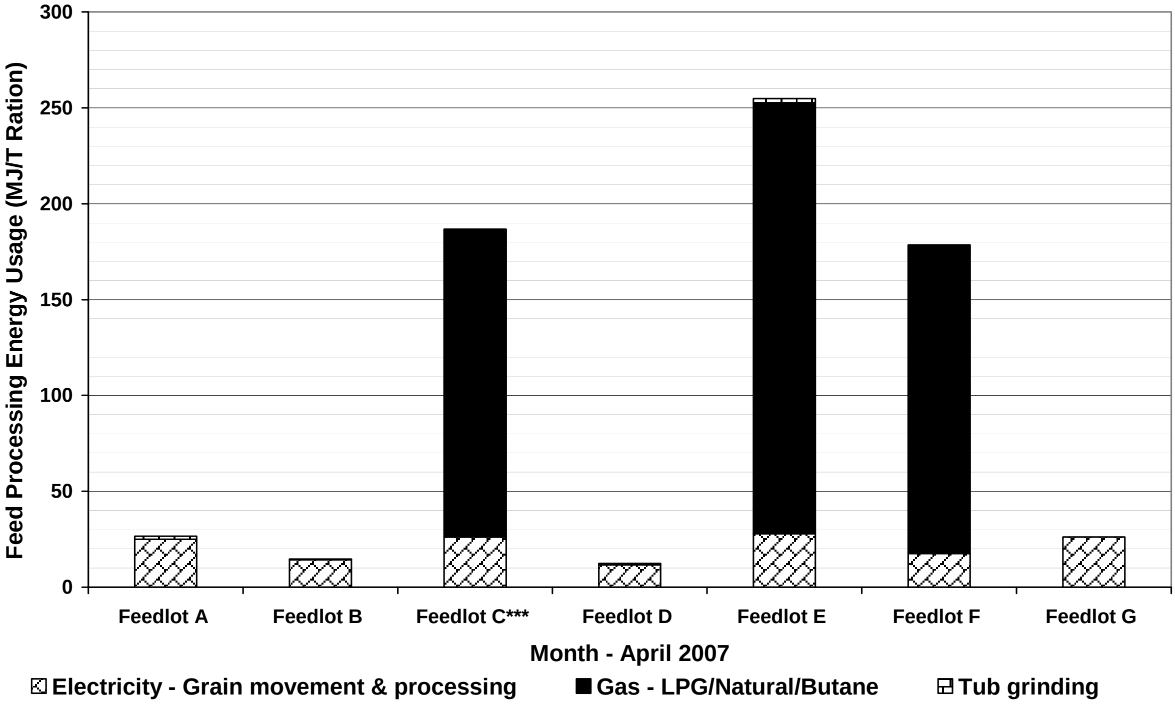


**Figure 92 – Feed processing energy consumption for April 2007 (MJ/t ration)**

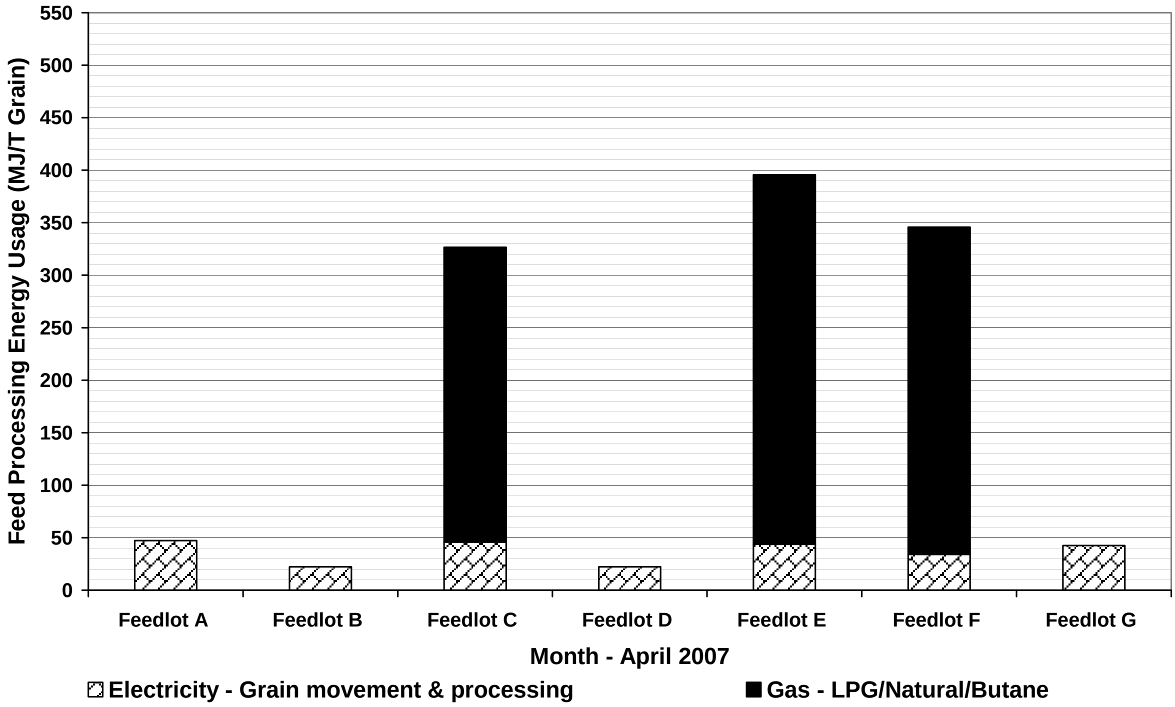


**Figure 93 – Feed processing energy consumption for April 2007 (MJ/t grain)**

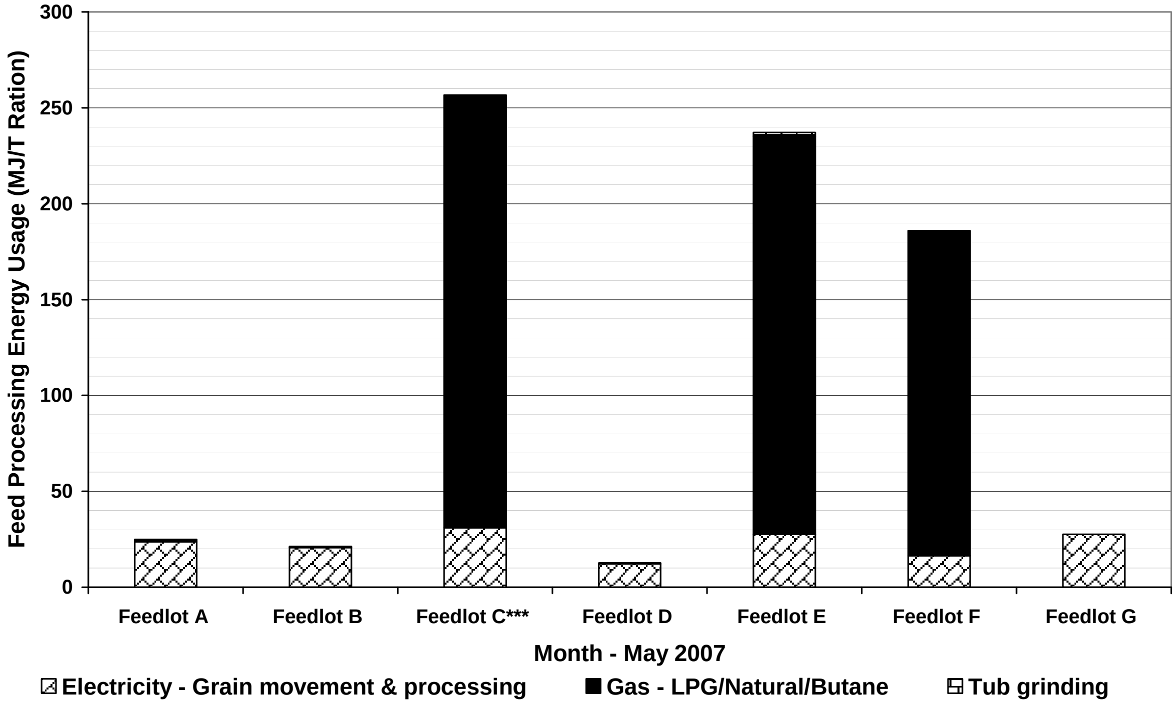


**Figure 94 – Feed processing energy consumption for May 2007 (MJ/t ration)**

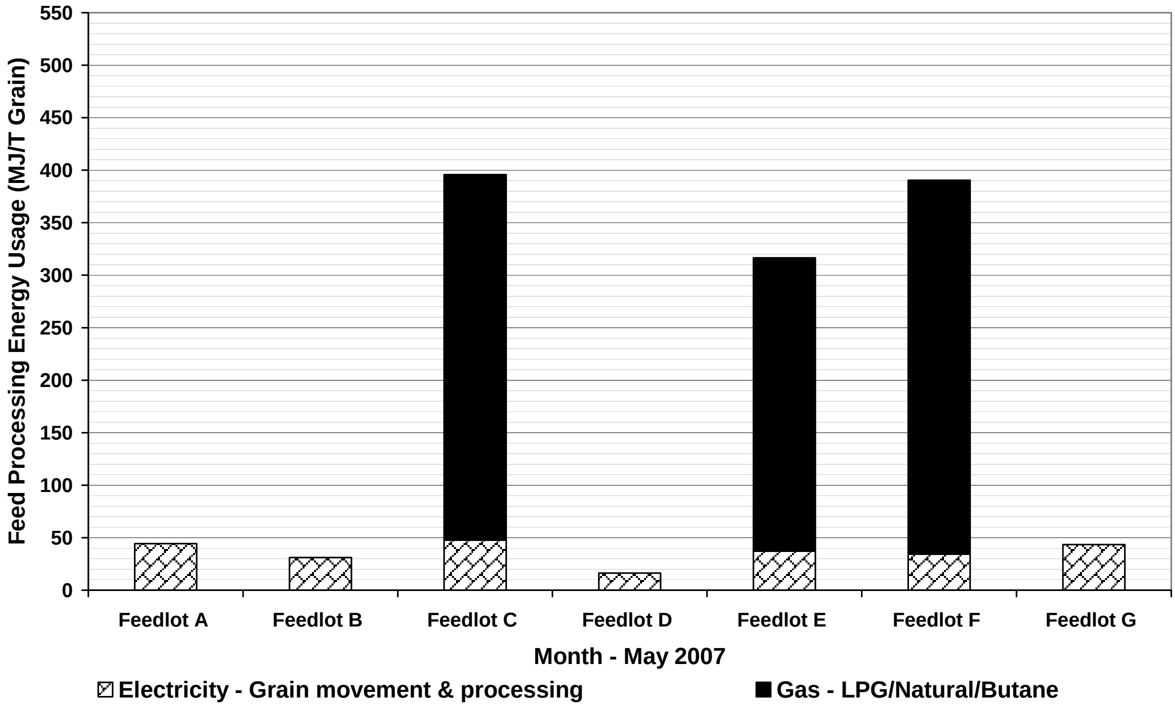


**Figure 95 – Feed processing energy consumption for May 2007 (MJ/t grain)**

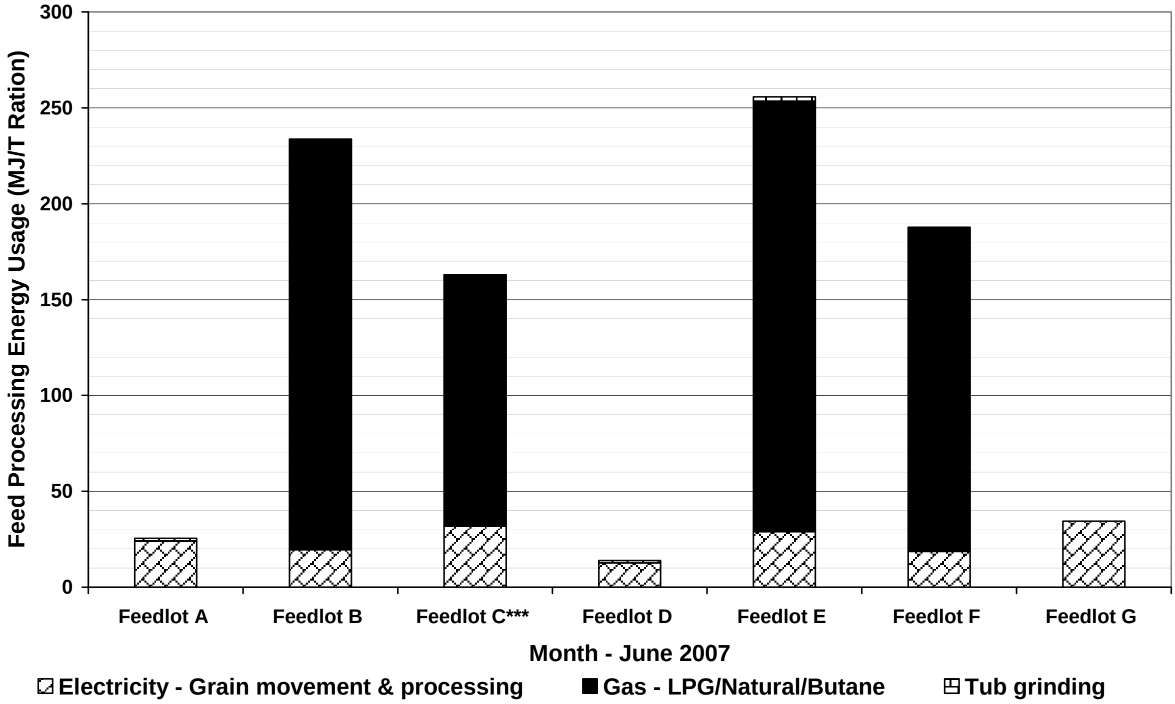


**Figure 96 – Feed processing energy consumption for June 2007 (MJ/t ration)**

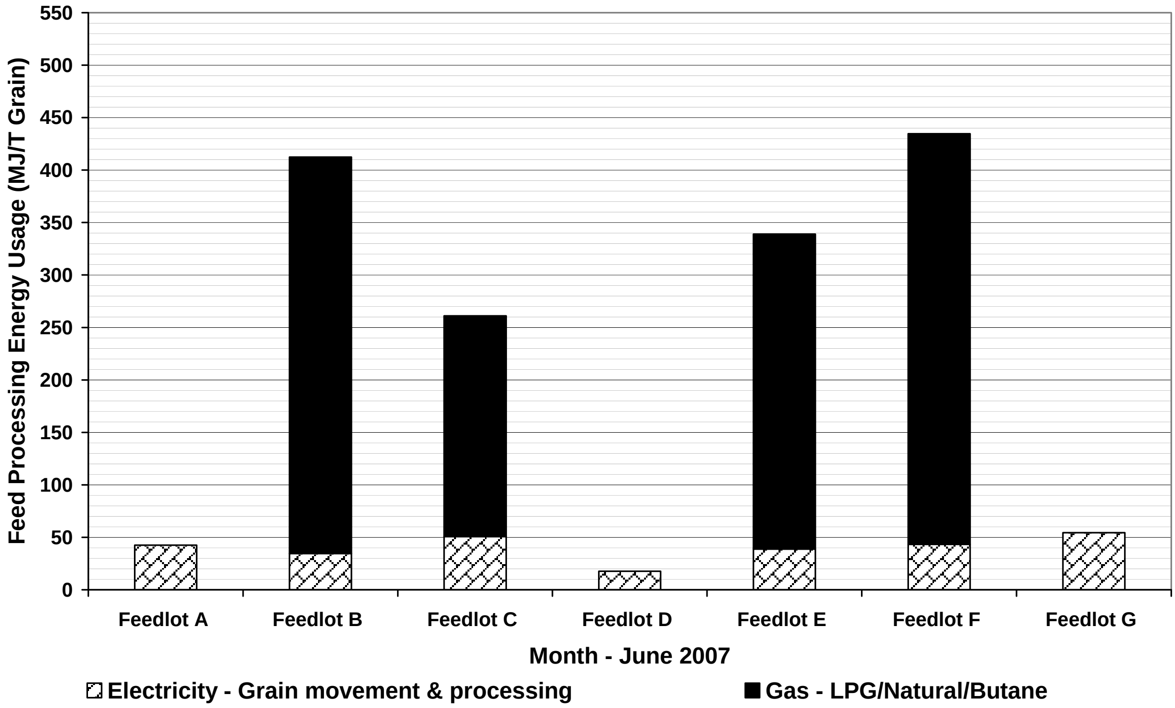


**Figure 97 – Feed processing energy consumption for June 2007 (MJ/t grain)**

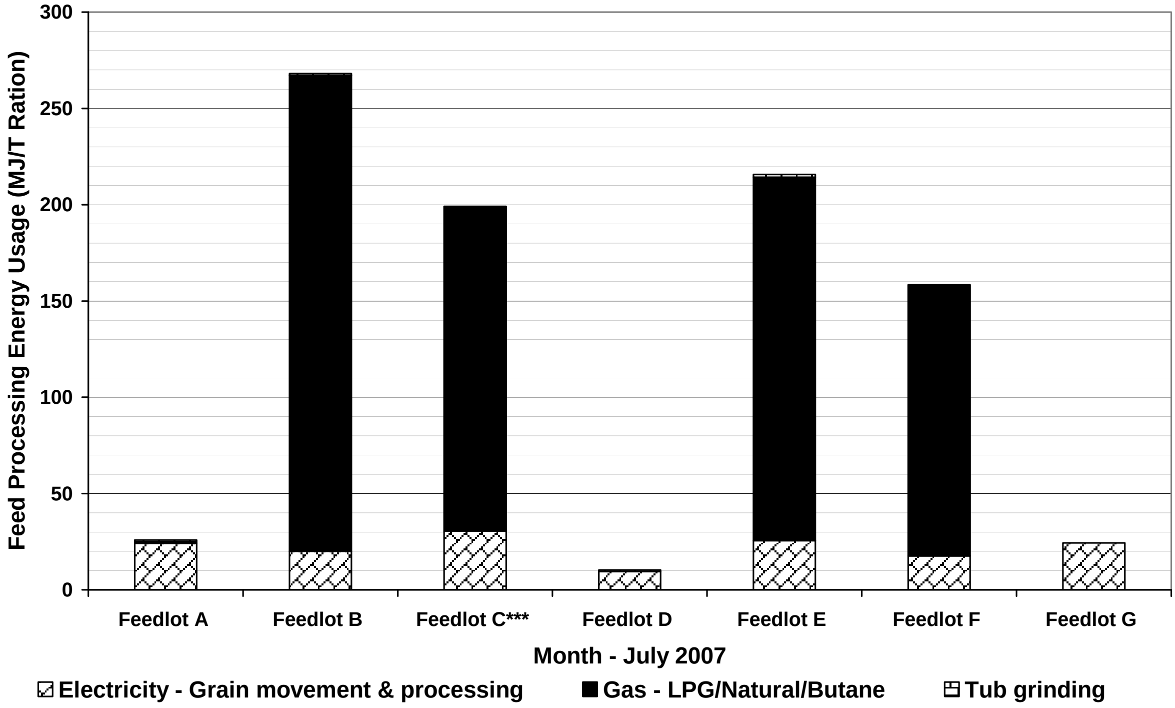


**Figure 98 – Feed processing energy consumption for July 2007 (MJ/t ration)**

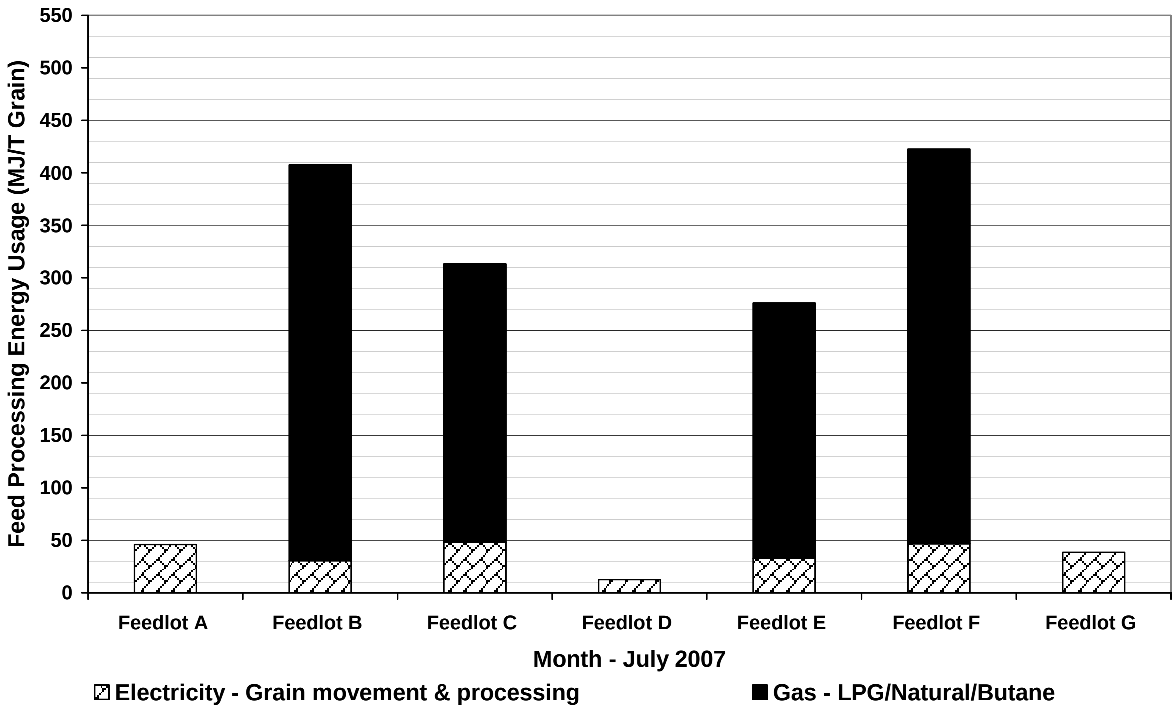


**Figure 99 – Feed processing energy consumption for July 2007 (MJ/t grain)**

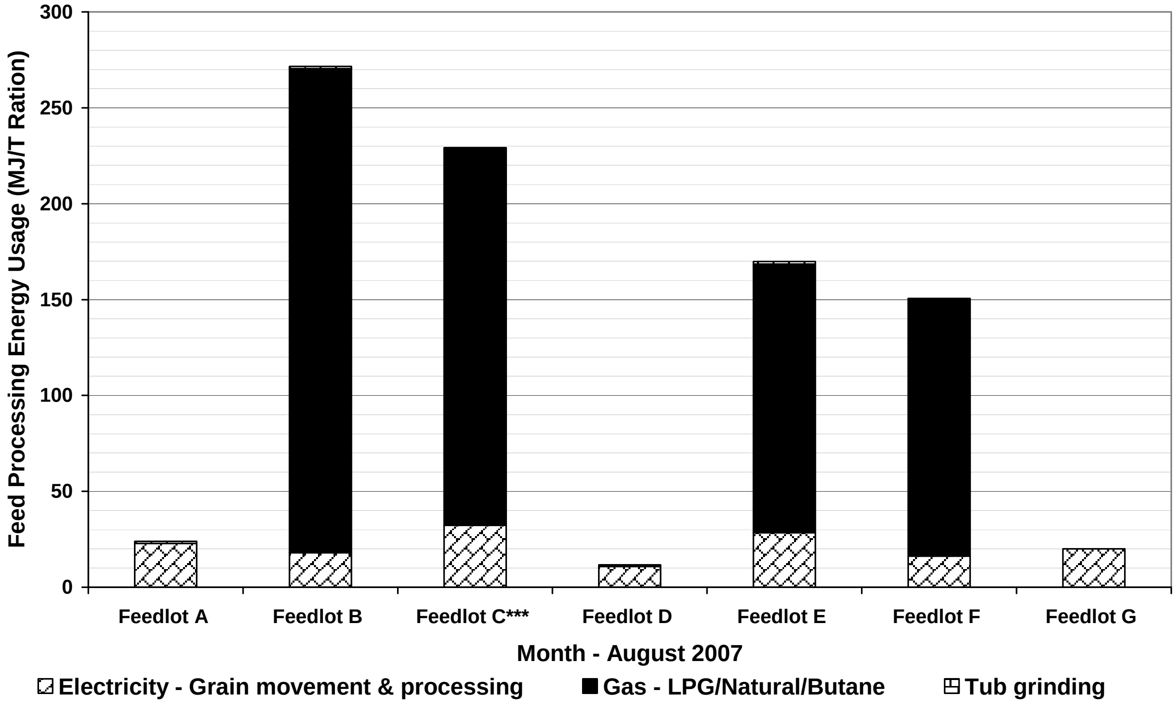


**Figure 100 – Feed processing energy consumption for August 2007 (MJ/t ration)**

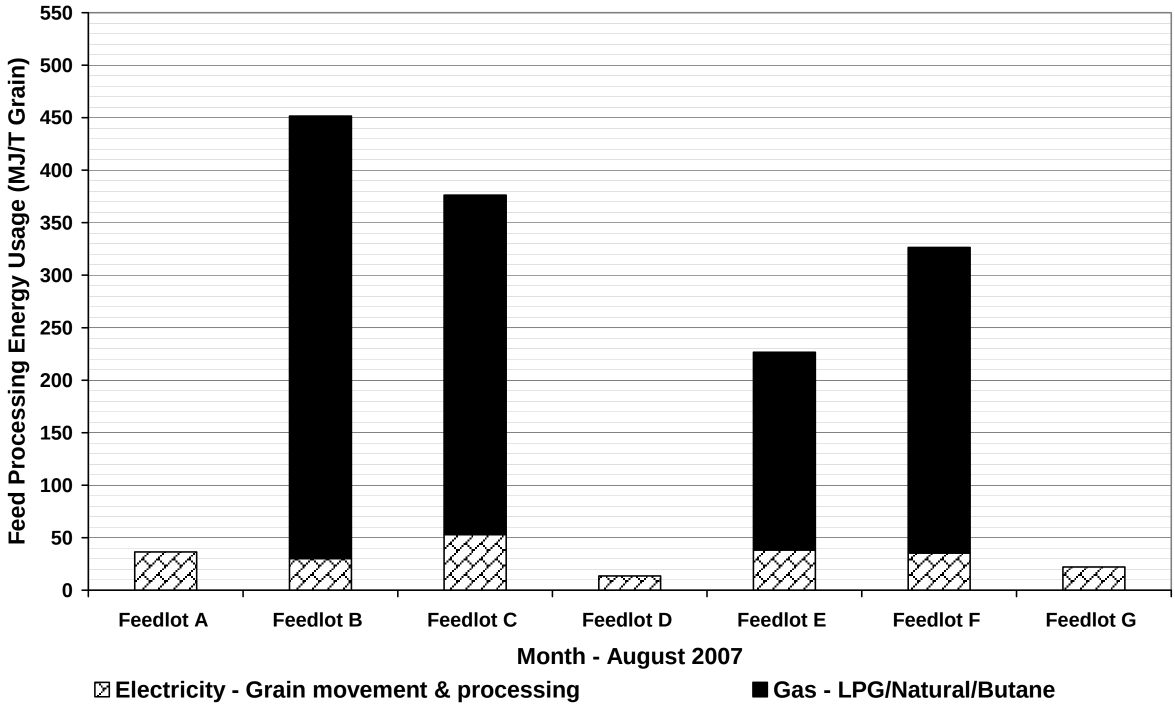


**Figure 101 – Feed processing energy consumption for August 2007 (MJ/t grain)**

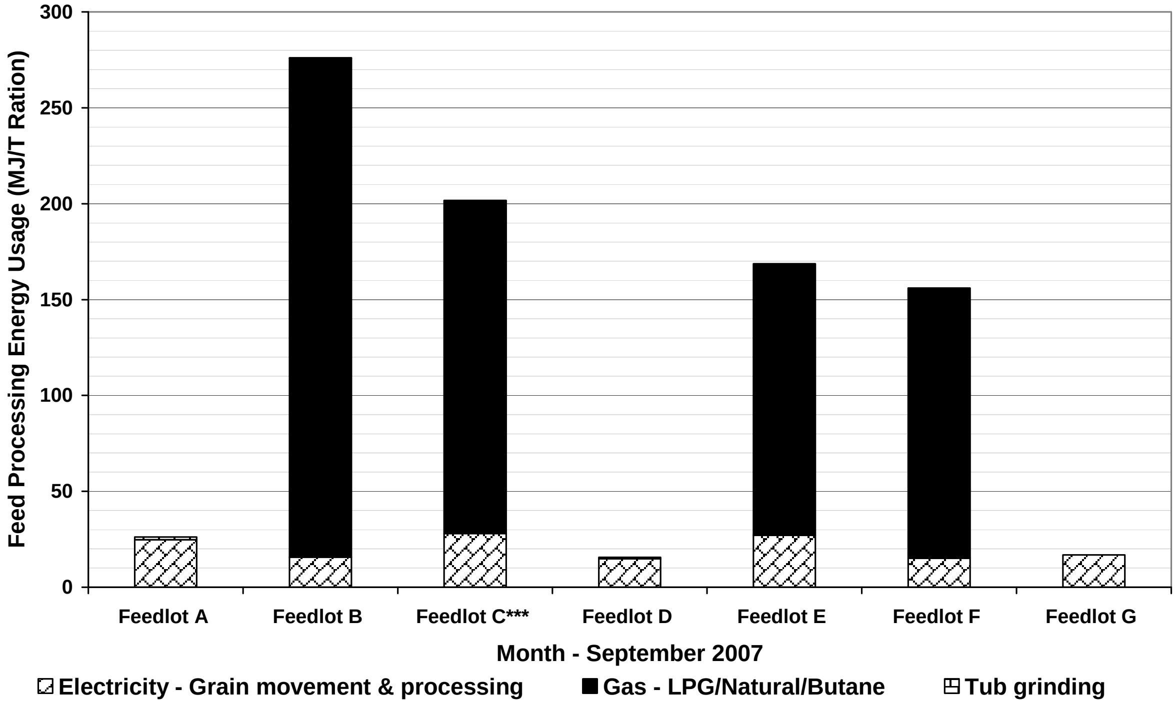


**Figure 102 – Feed processing energy consumption for September 2007 (MJ/t ration)**

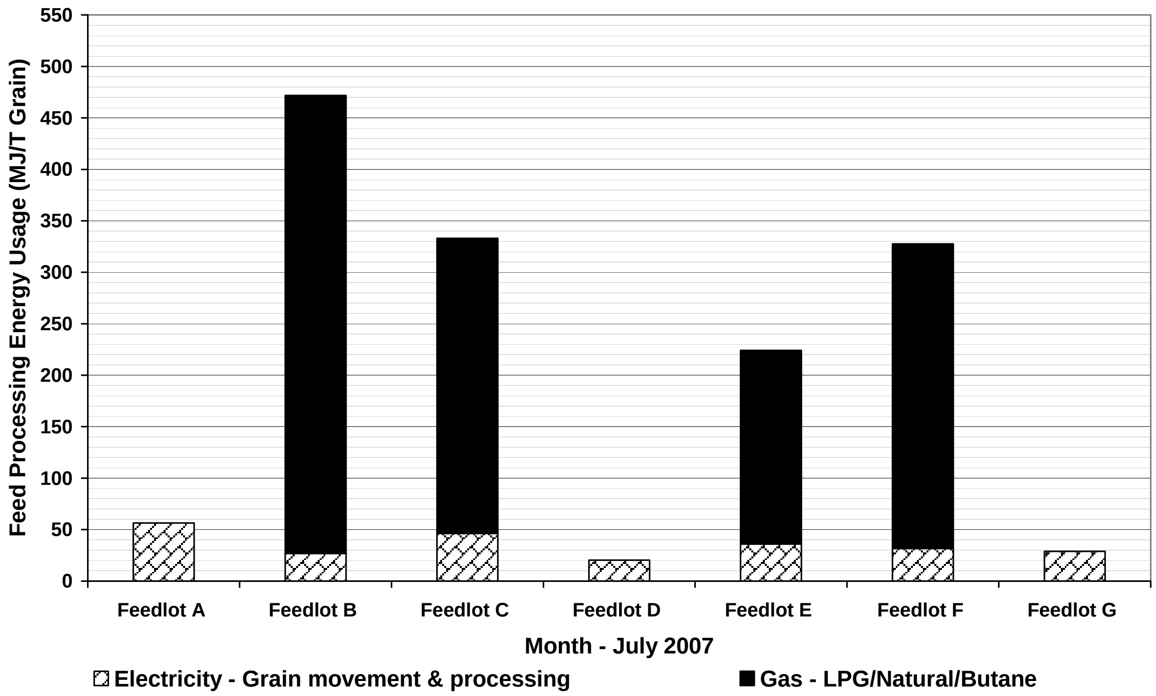


**Figure 103 – Feed processing energy consumption for September 2007 (MJ/t grain)**

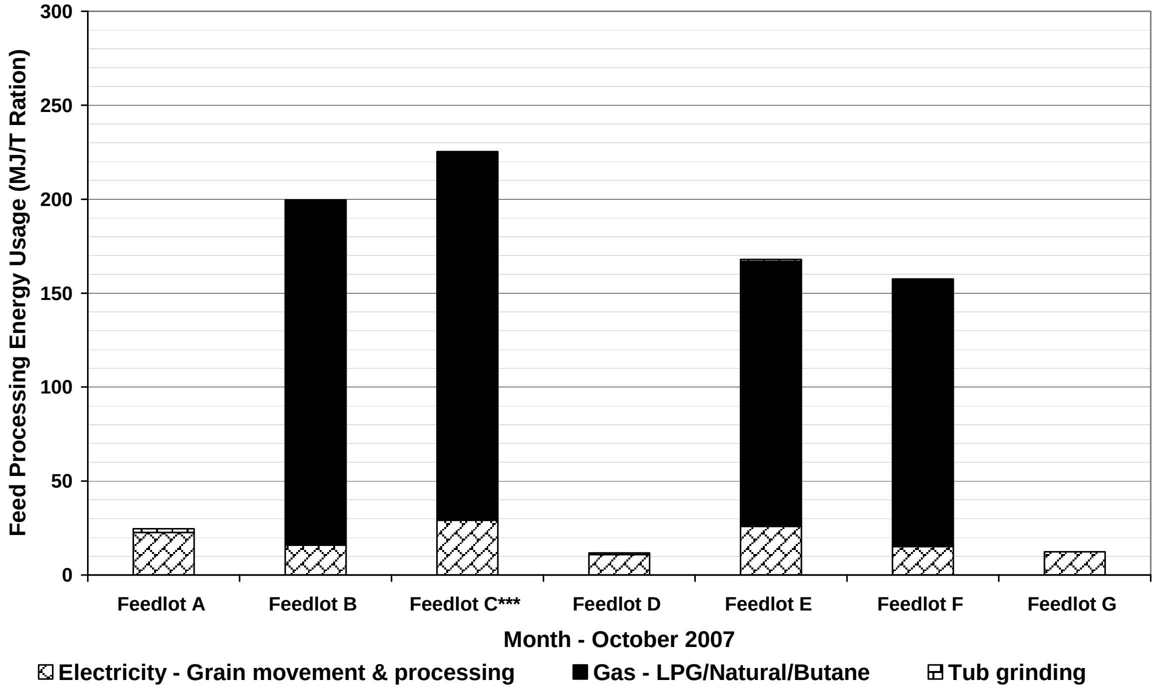


**Figure 104 – Feed processing energy consumption for October 2007 (MJ/t ration)**

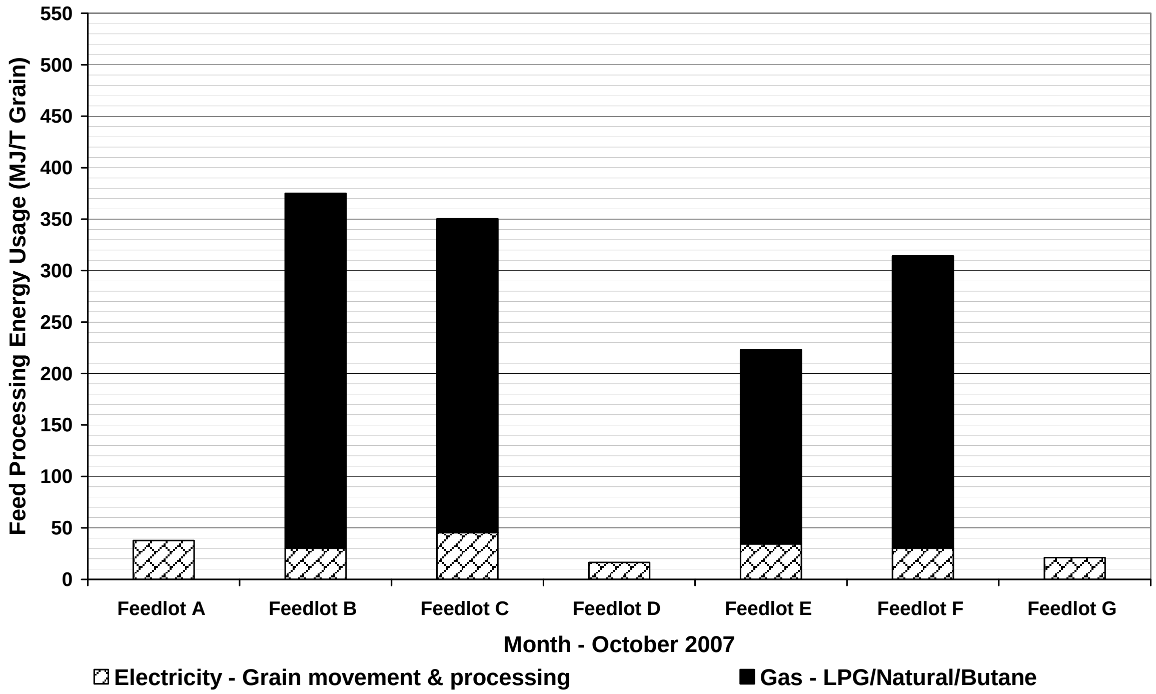


**Figure 105 – Feed processing energy consumption for October 2007 (MJ/t grain)**

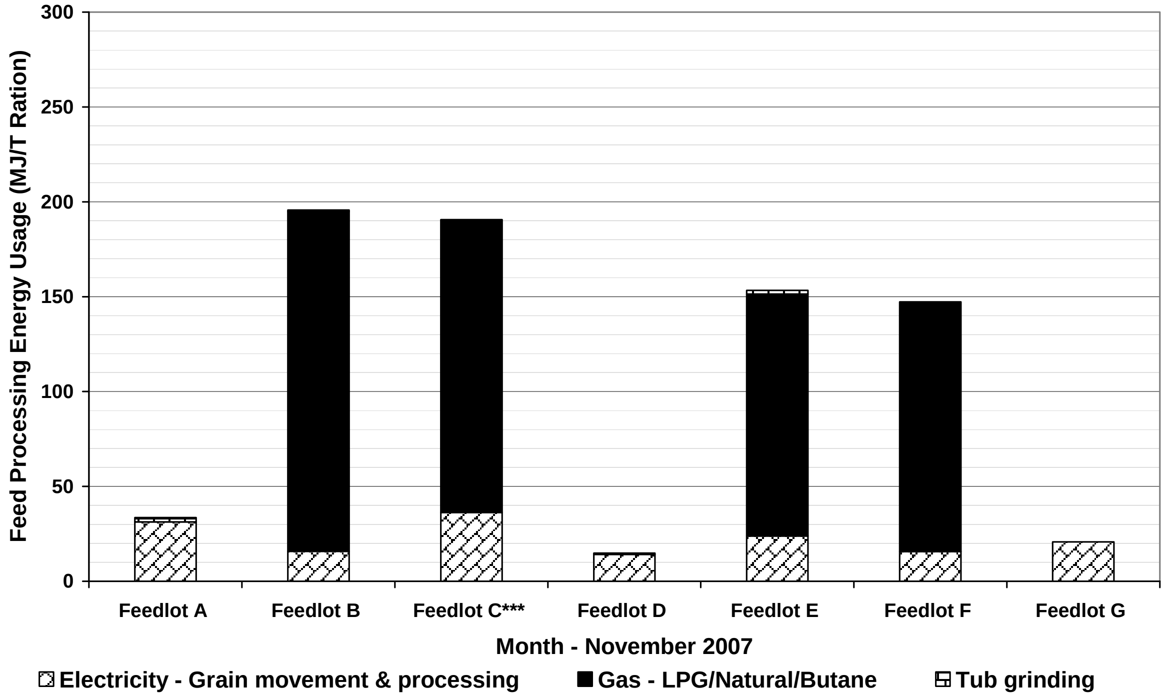


**Figure 106 – Feed processing energy consumption for November 2007 (MJ/t ration)**

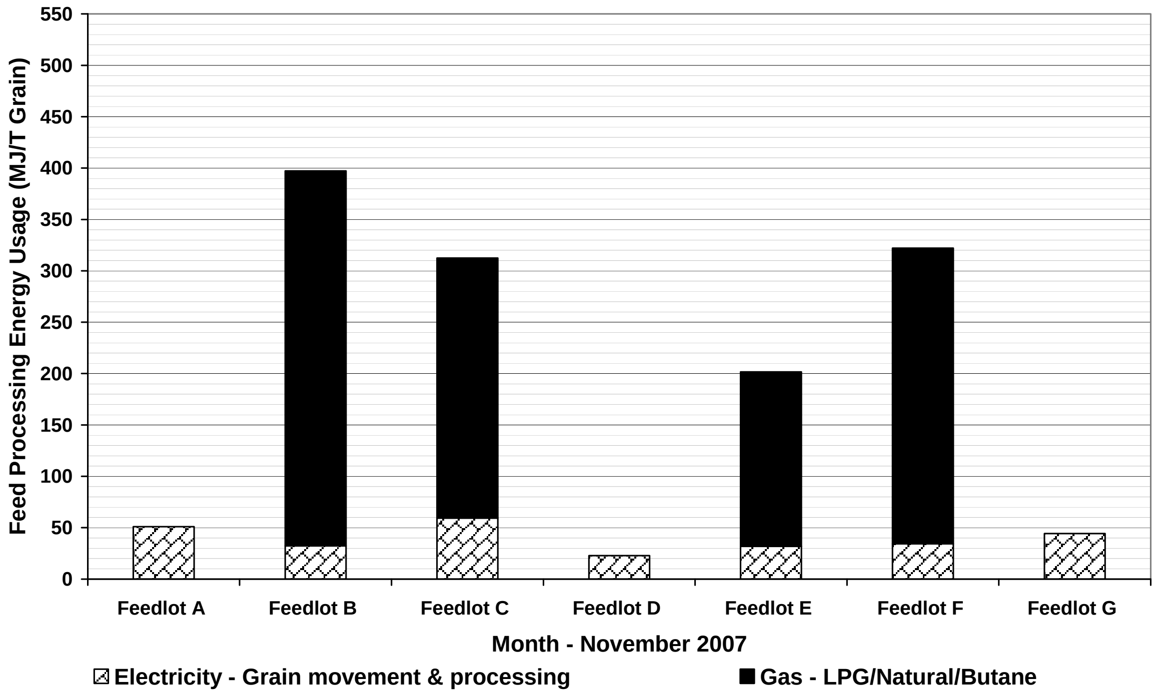


**Figure 107 – Feed processing energy consumption for November 2007 (MJ/t grain)**

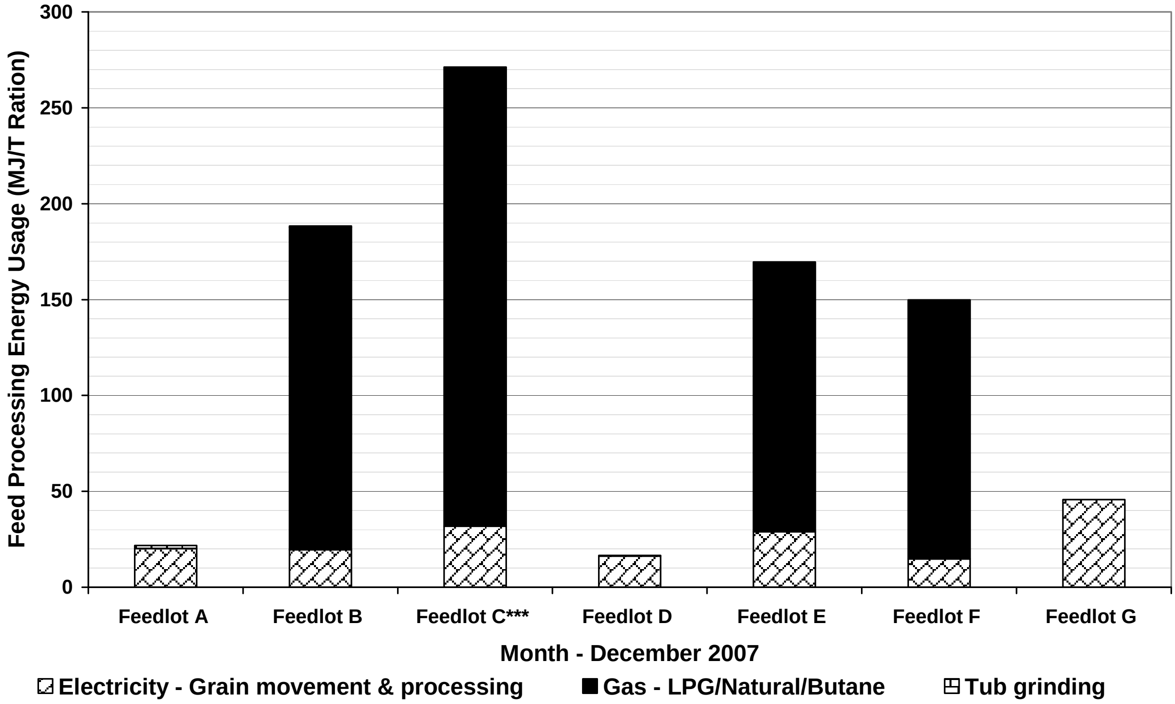


**Figure 108 – Feed processing energy consumption for December 2007 (MJ/t ration)**

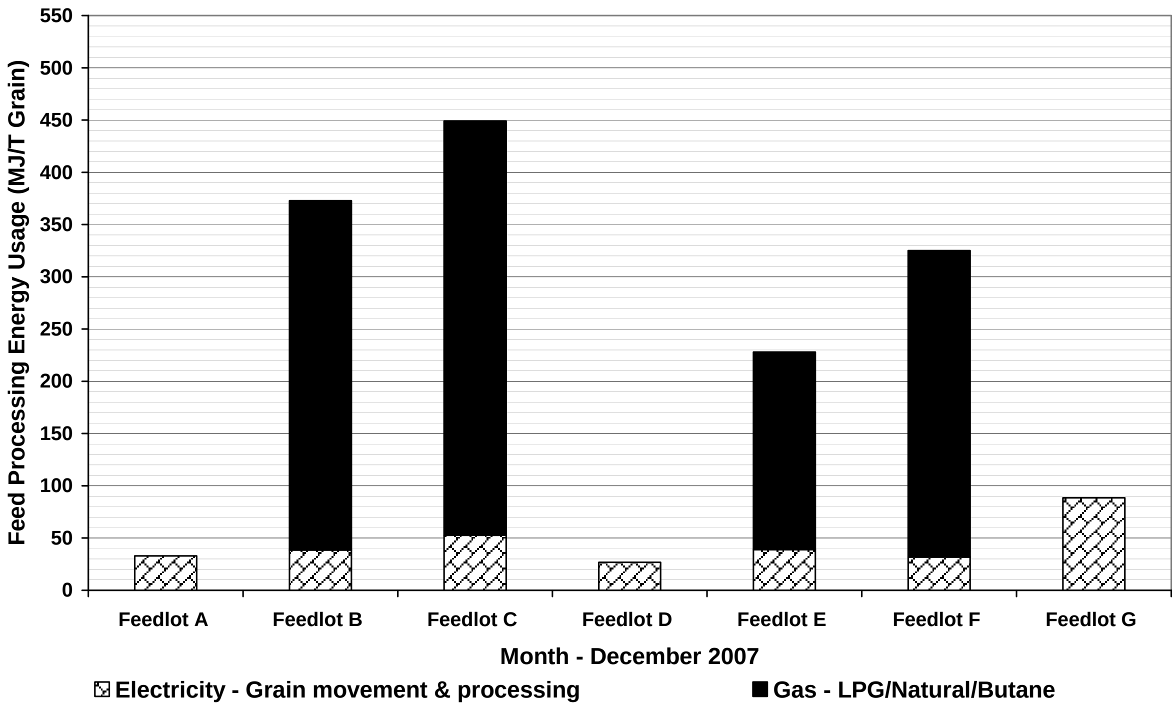


**Figure 109 – Feed processing energy consumption for December 2007 (MJ/t grain)**

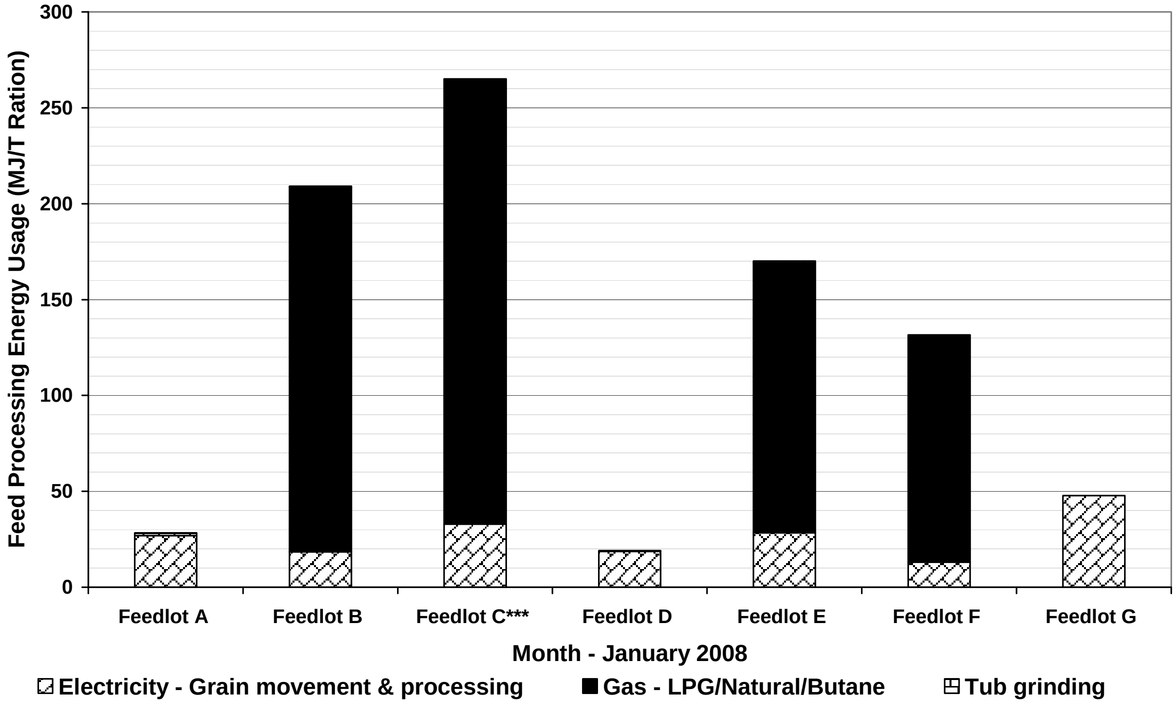


**Figure 110 – Feed processing energy consumption for January 2008 (MJ/t ration)**

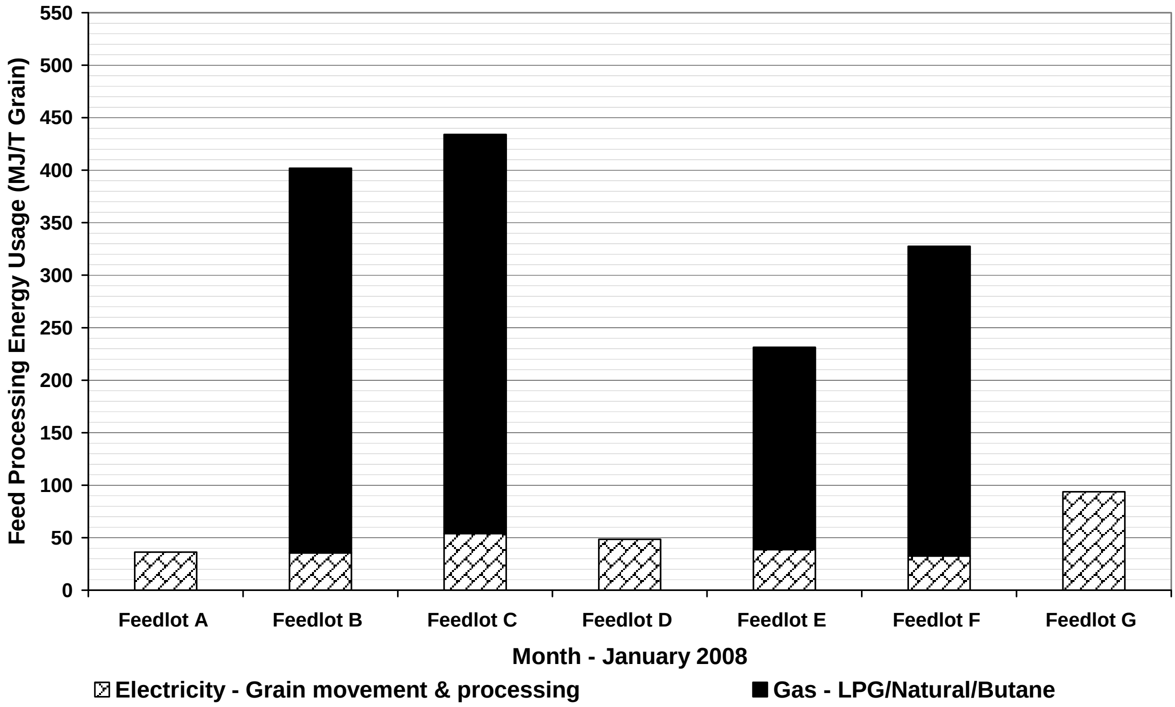


**Figure 111 – Feed processing energy consumption for January 2008 (MJ/t grain)**

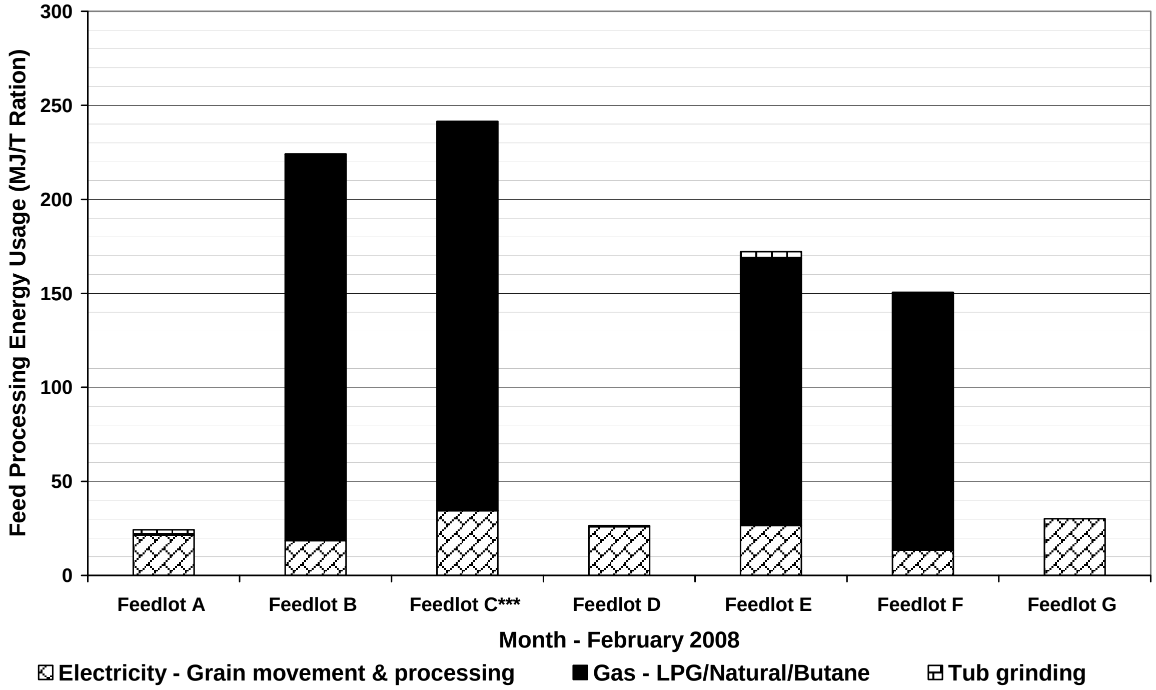


**Figure 112 – Feed processing energy consumption for February 2008 (MJ/t ration)**

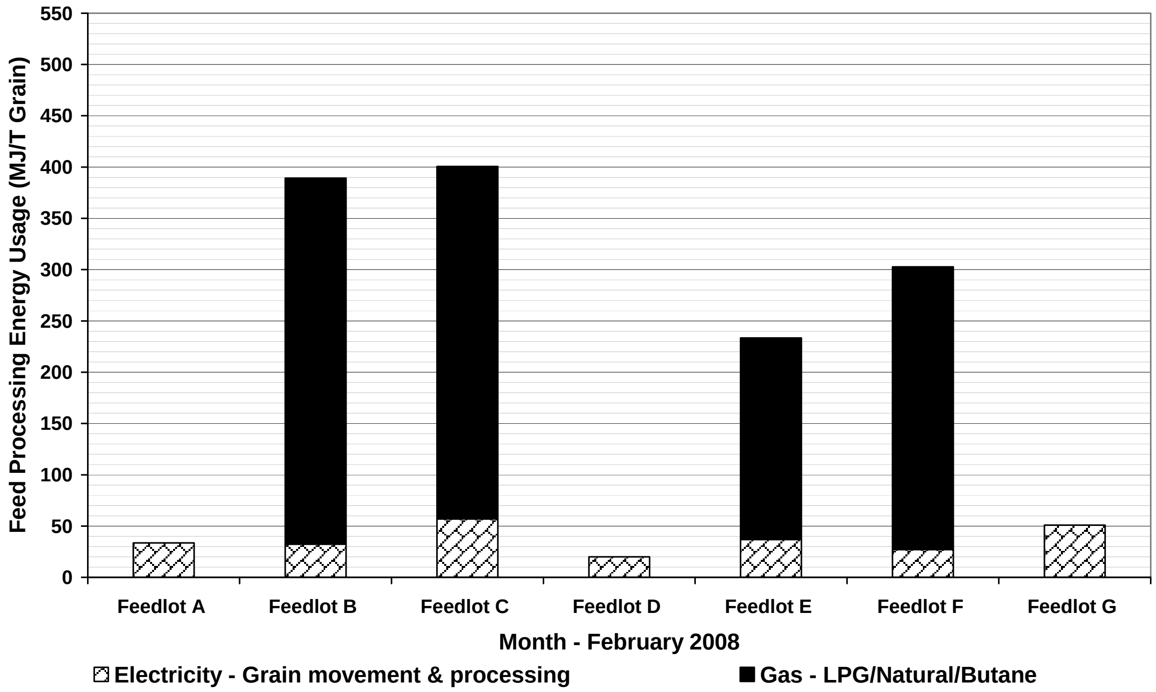


**Figure 113 – Feed processing energy consumption for February 2008 (MJ/t grain)**

## Appendix C.2 – Feed delivery energy usage

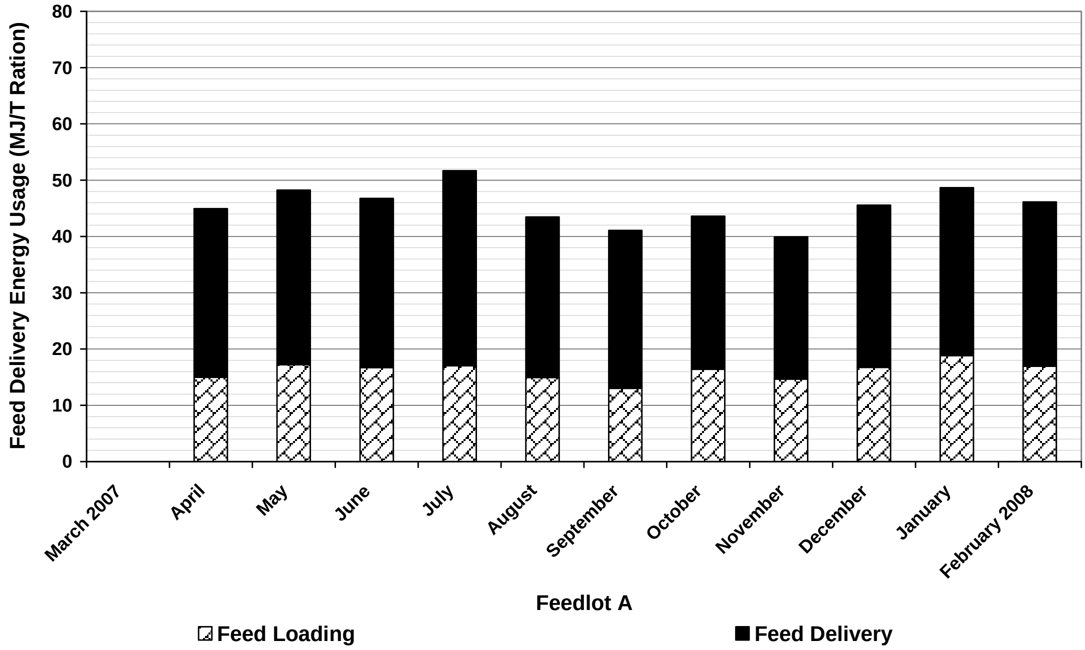


**Figure 114 – Feed delivery energy consumption for Feedlot A (MJ/t ration)**

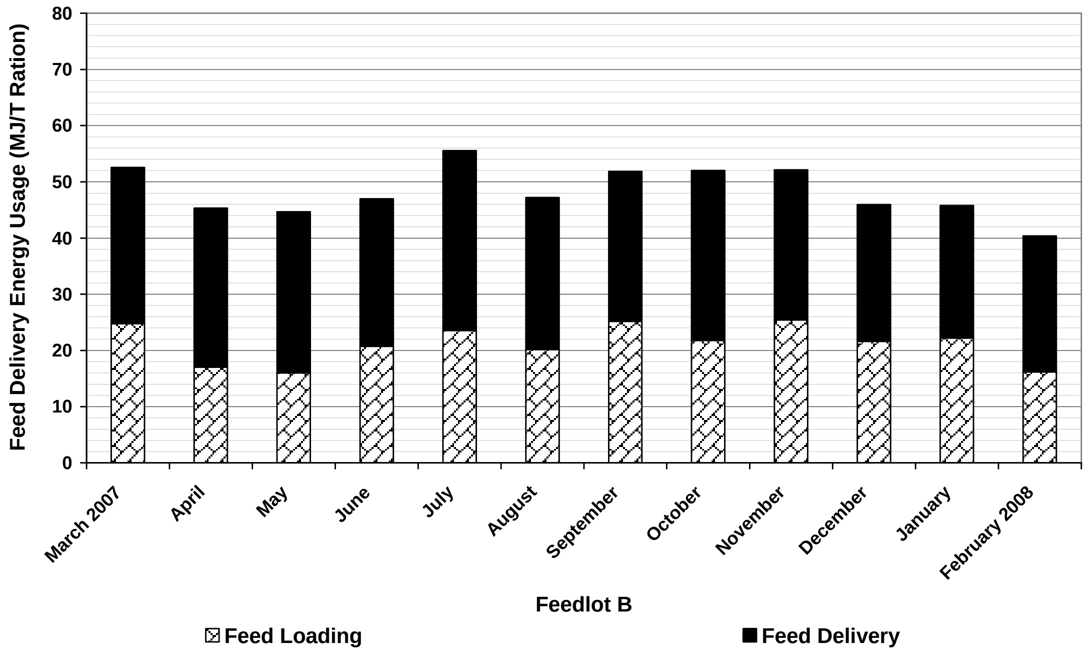


**Figure 115 – Feed delivery energy consumption for Feedlot B (MJ/t ration)**

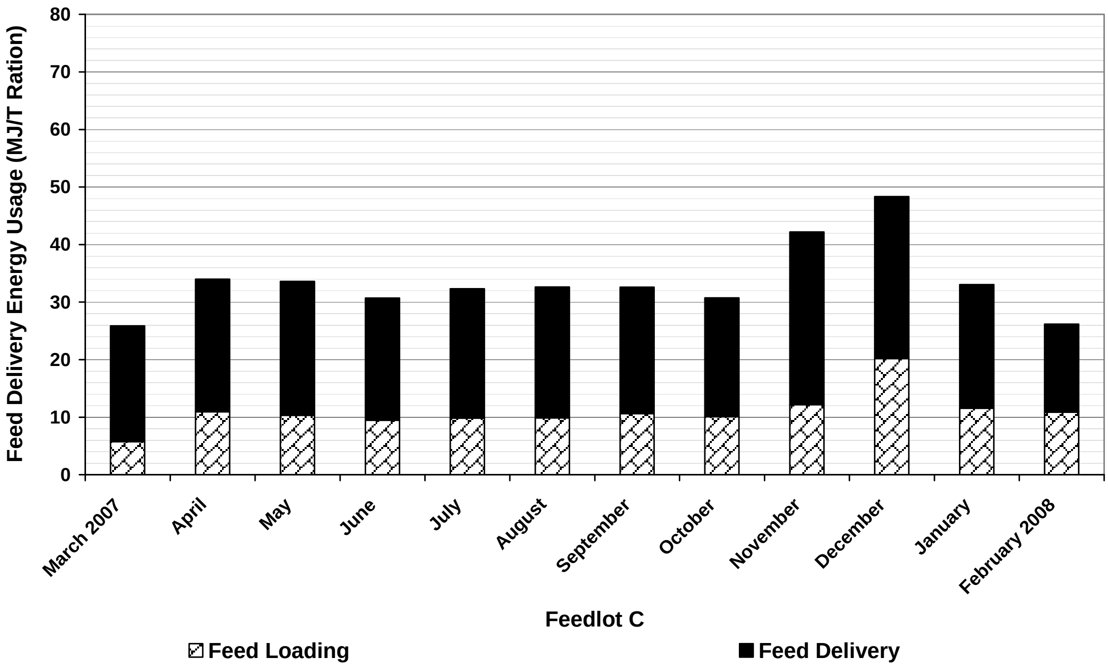


**Figure 116 – Feed delivery energy consumption for Feedlot C (MJ/t ration)**

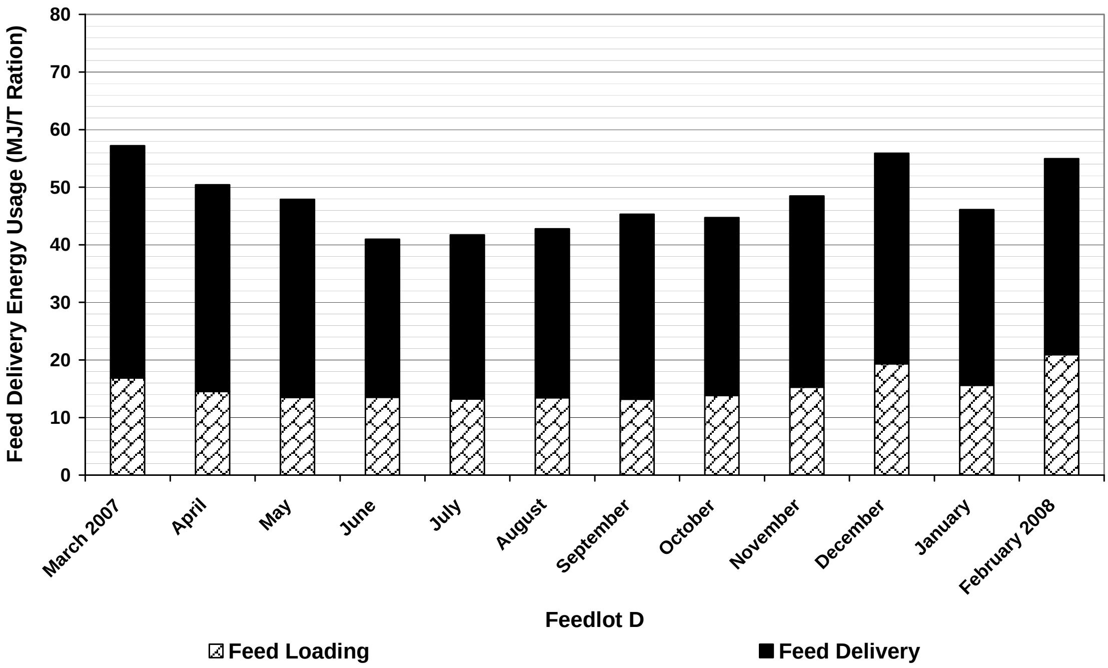


**Figure 117 – Feed delivery energy consumption for Feedlot D (MJ/t ration)**

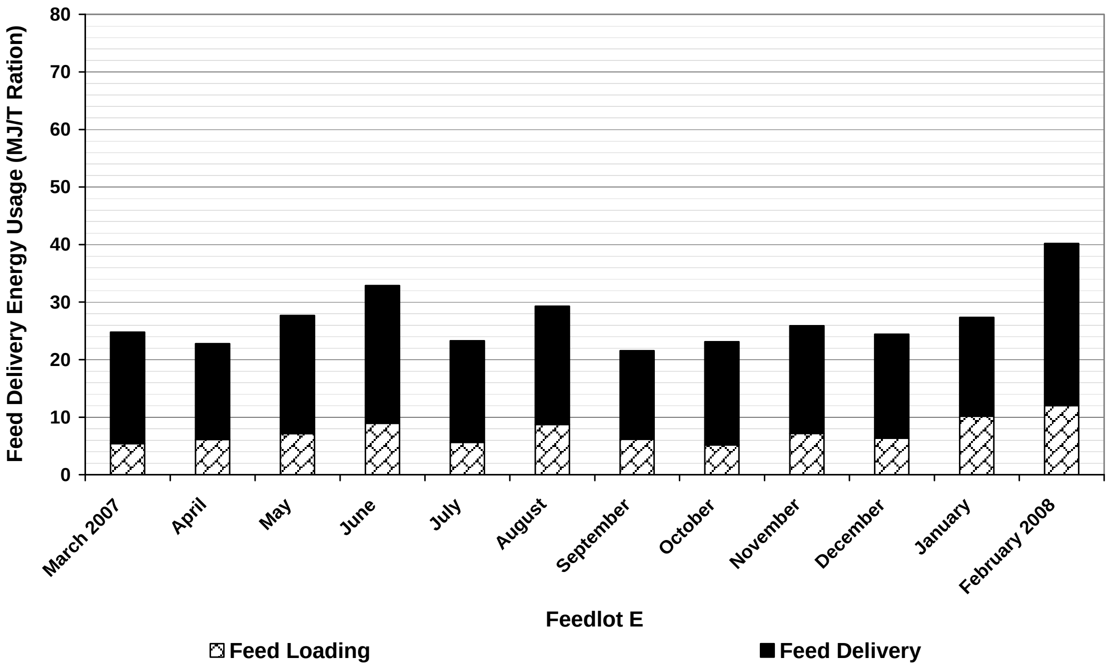


**Figure 118 – Feed delivery energy consumption for Feedlot E (MJ/t ration)**

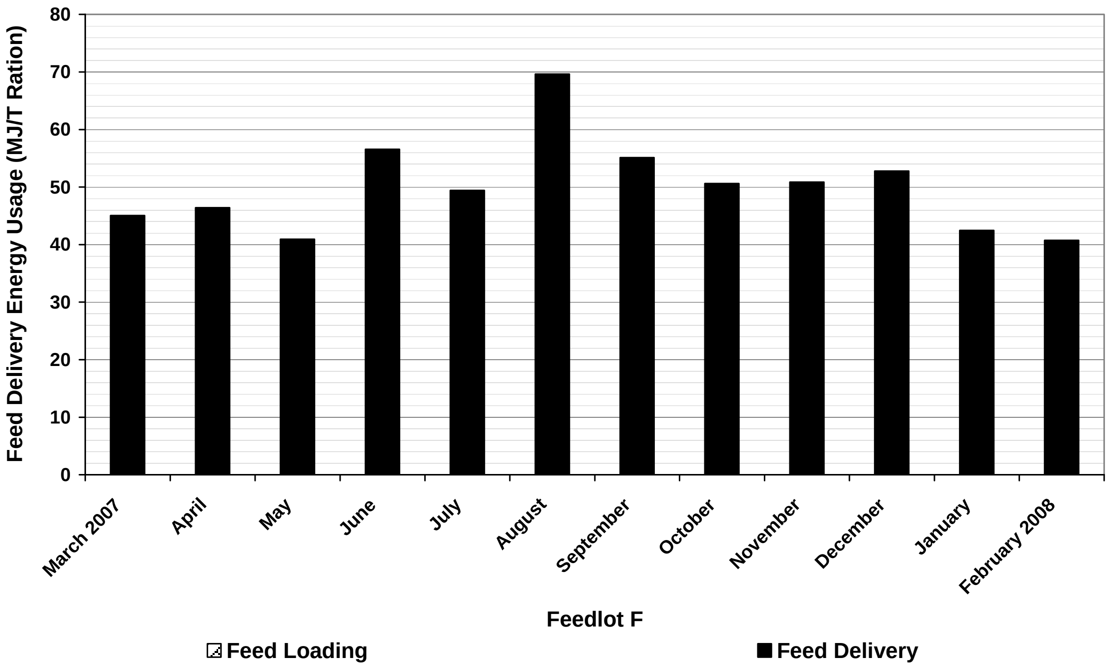


**Figure 119 – Feed delivery energy consumption for Feedlot F (MJ/t ration)**

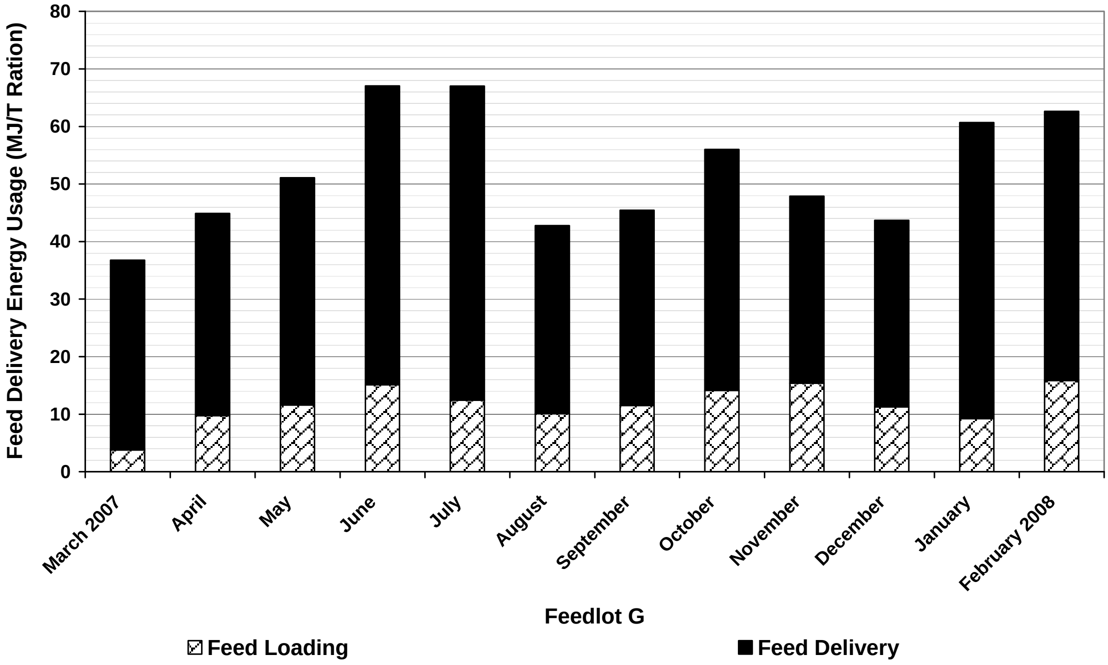


**Figure 120 – Feed delivery energy consumption for Feedlot G (MJ/t ration)**

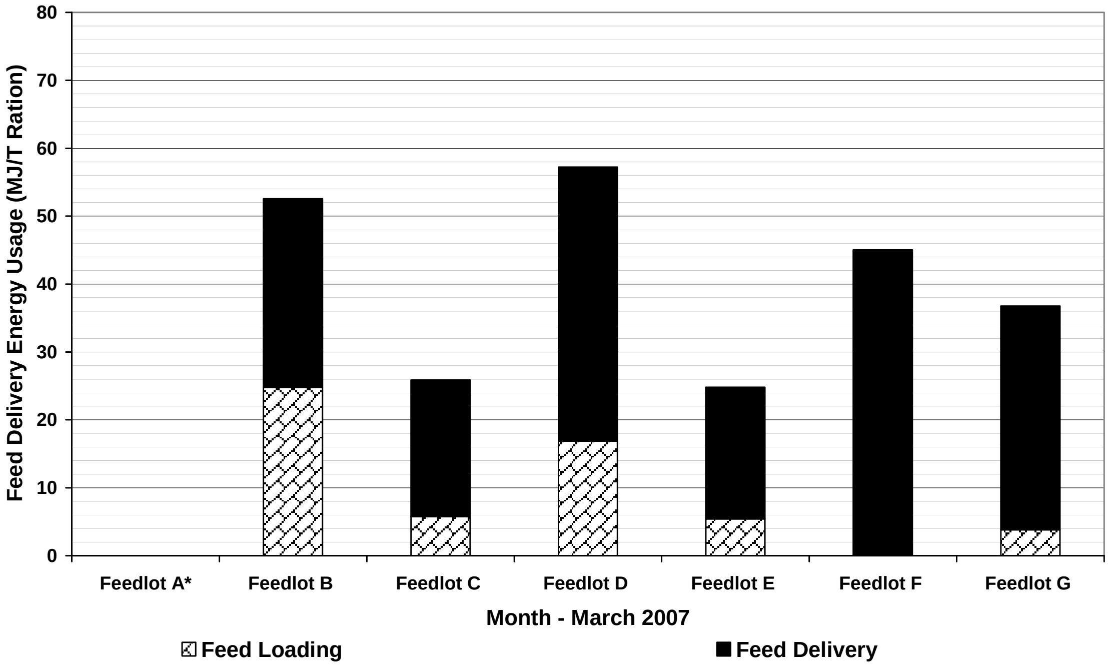


**Figure 121 – Feed delivery energy consumption for March 2007 (MJ/t ration)**

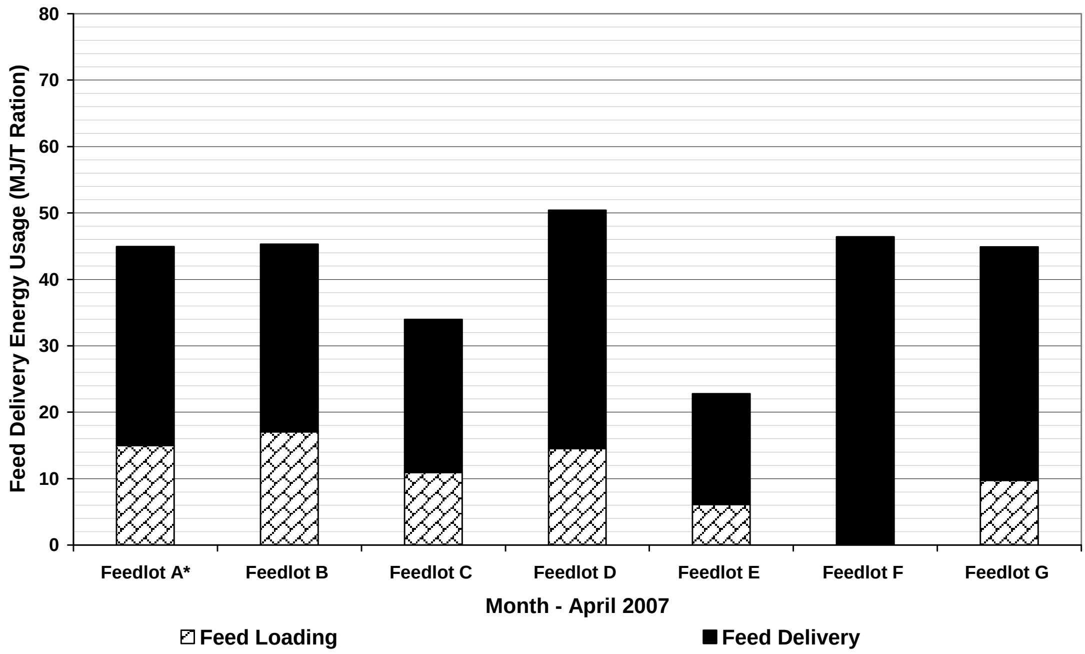


**Figure 122 – Feed delivery energy consumption for April 2007 (MJ/t ration)**

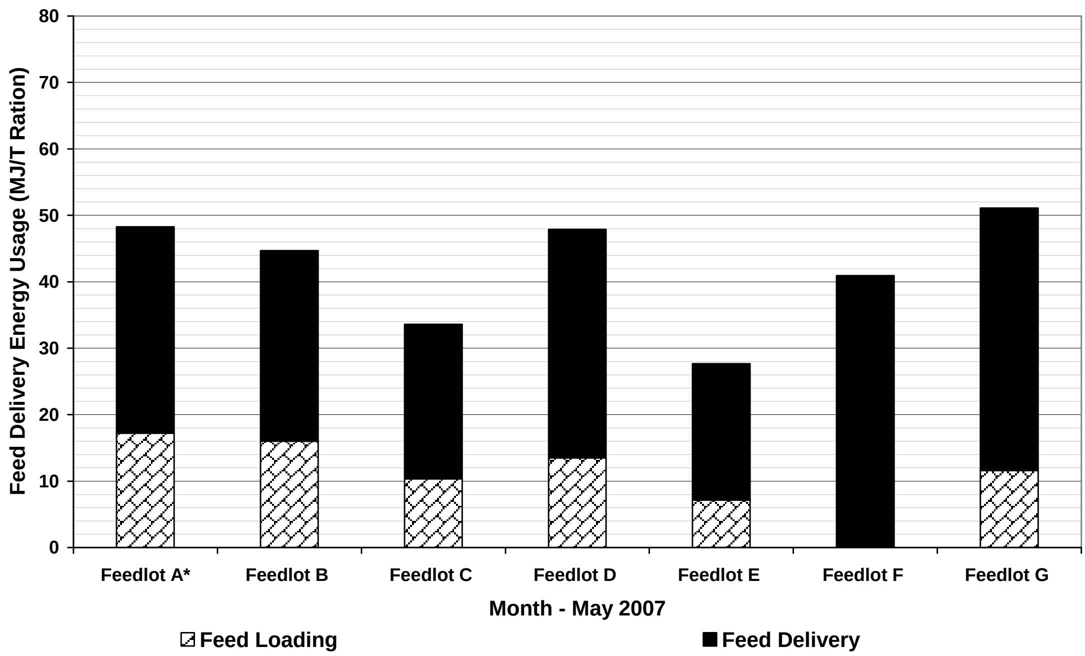


**Figure 123 – Feed delivery energy consumption for May 2007 (MJ/t ration)**

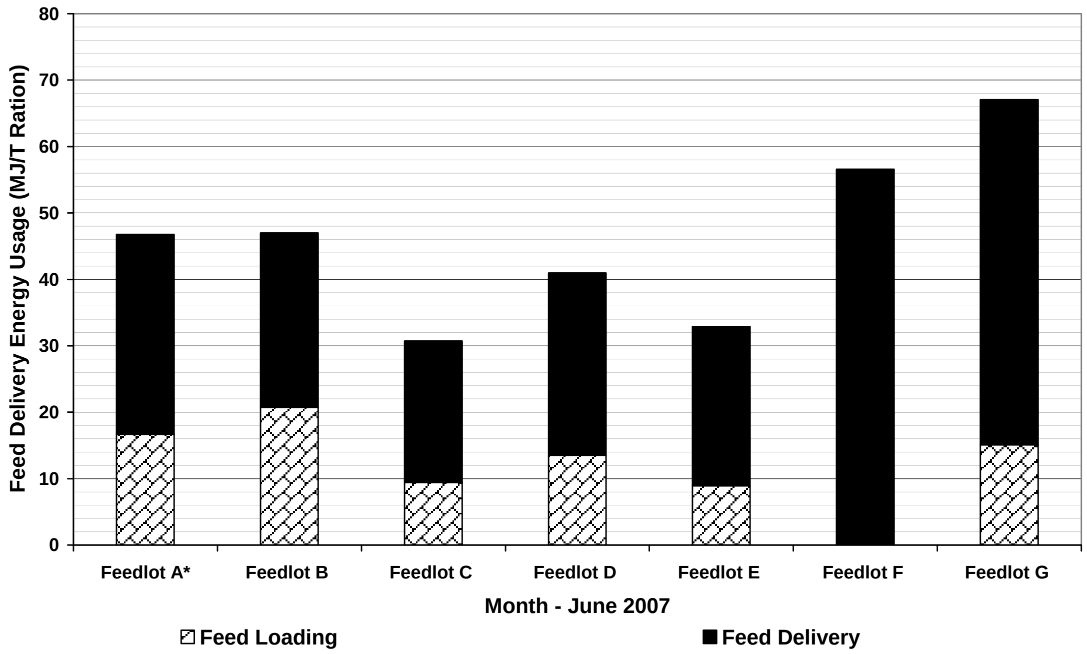


**Figure 124 – Feed delivery energy consumption for June 2007 (MJ/t ration)**

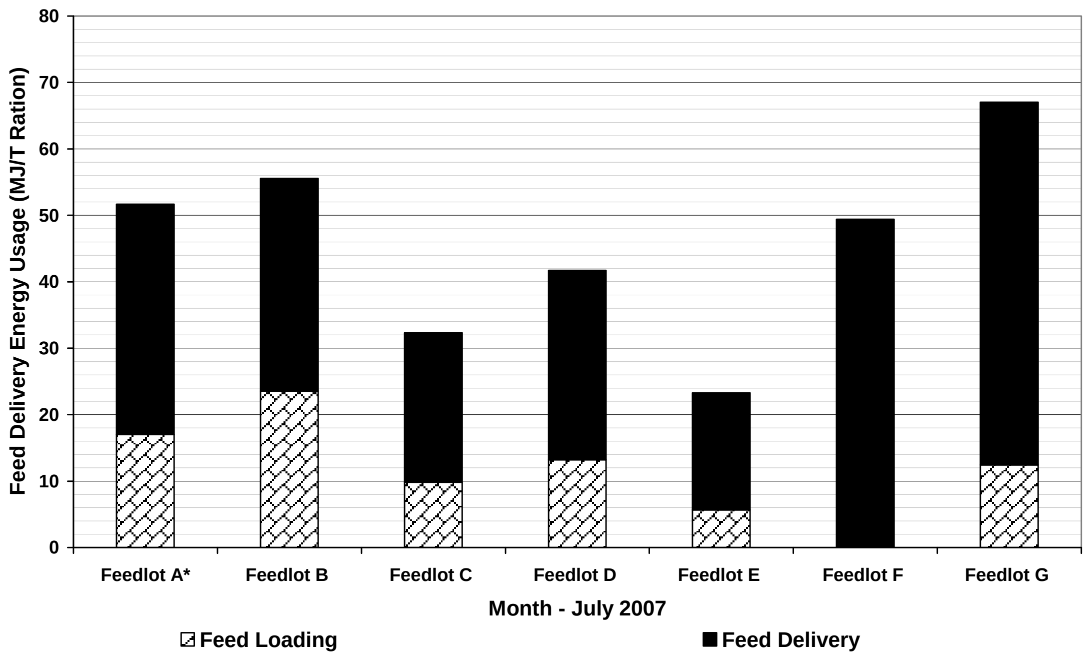


**Figure 125 – Feed delivery energy consumption for July 2007 (MJ/t ration)**

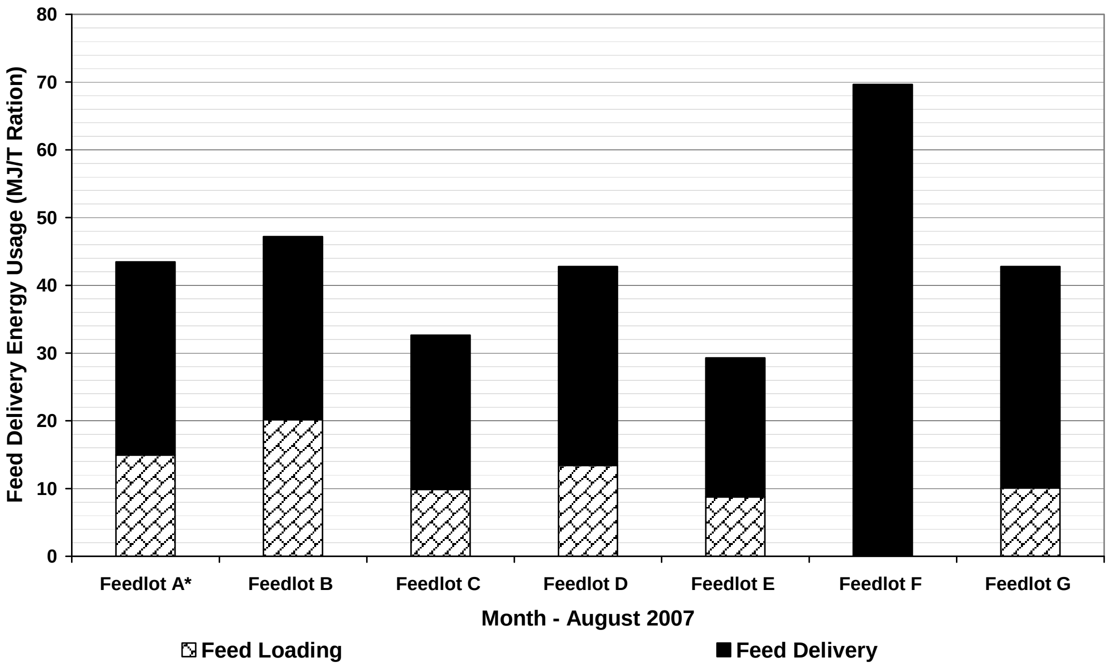


**Figure 126 – Feed delivery energy consumption for August 2007 (MJ/t ration)**

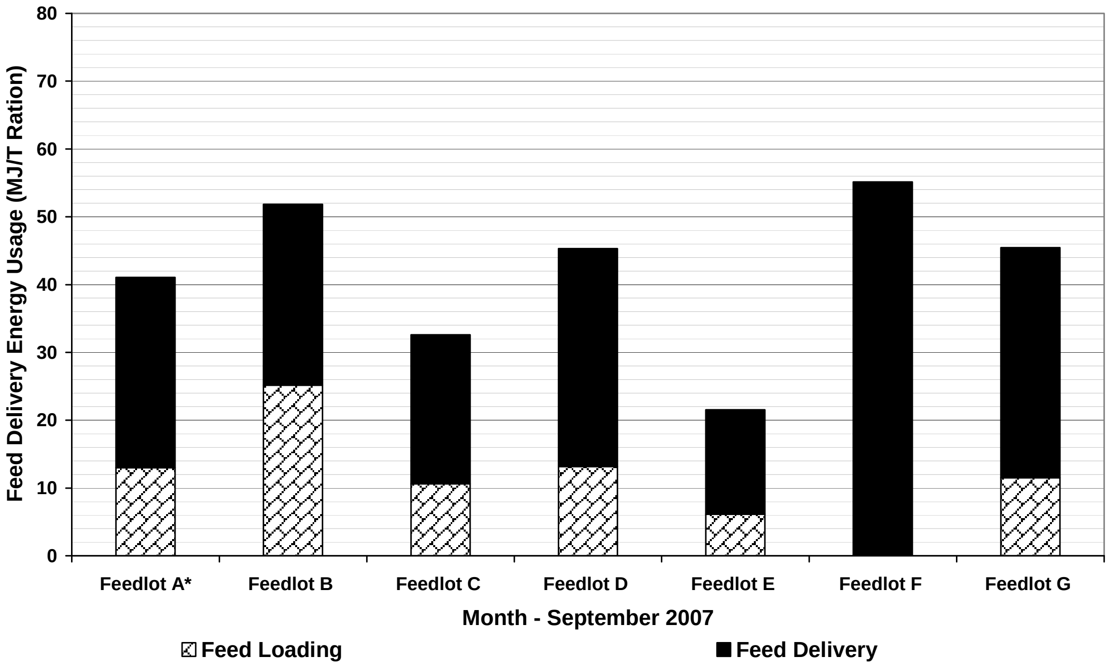


**Figure 127 – Feed delivery energy consumption for September 2007 (MJ/t ration)**

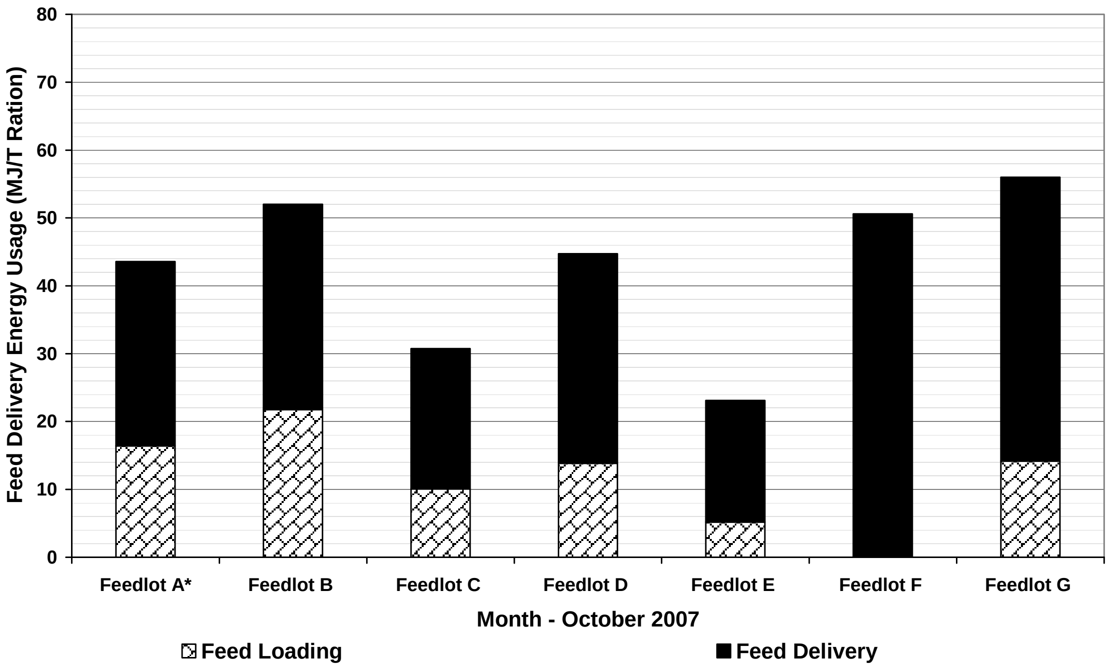


**Figure 128 – Feed delivery energy consumption for October 2007 (MJ/t ration)**

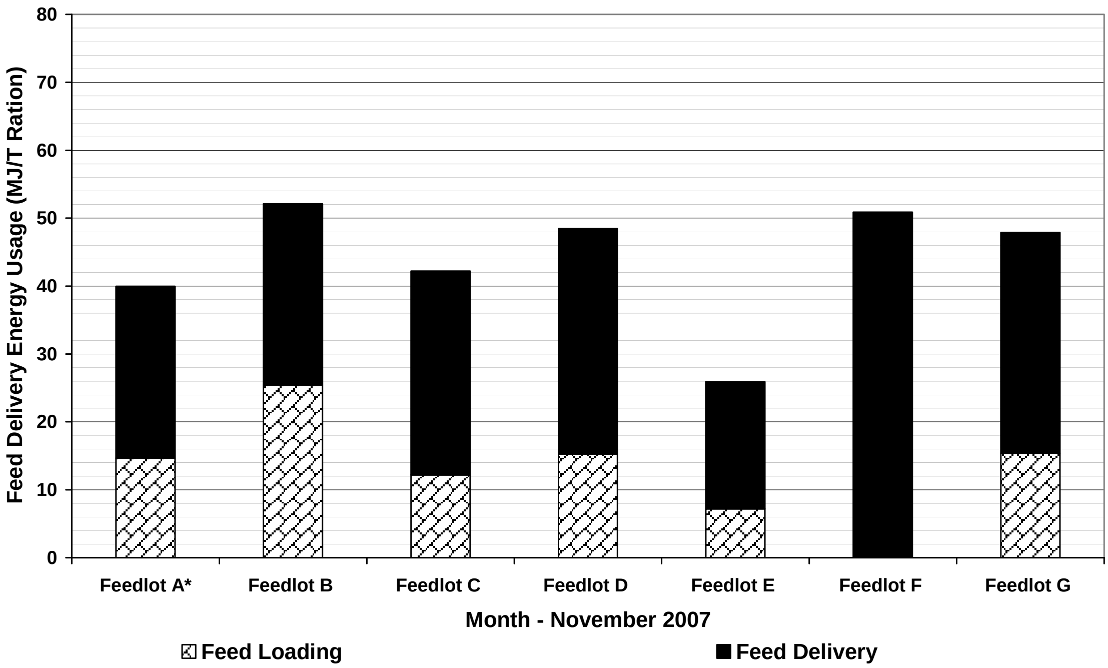


**Figure 129 – Feed delivery energy consumption for November 2007 (MJ/t ration)**

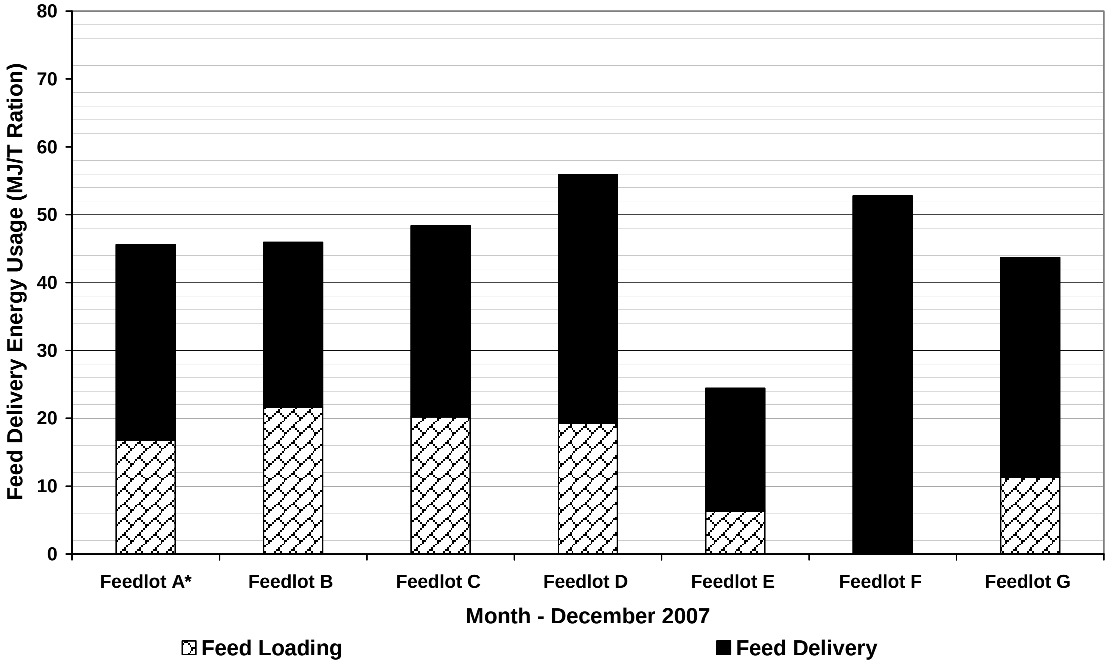


**Figure 130 – Feed delivery energy consumption for December 2007 (MJ/t ration)**

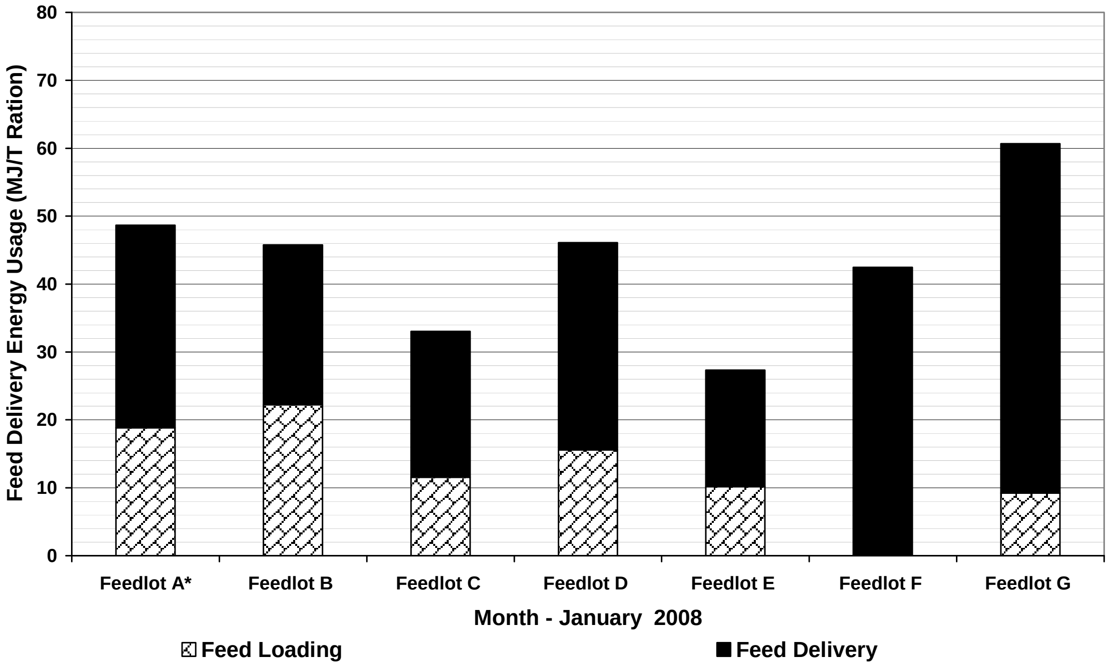


**Figure 131 – Feed delivery energy consumption for January 2008 (MJ/t ration)**

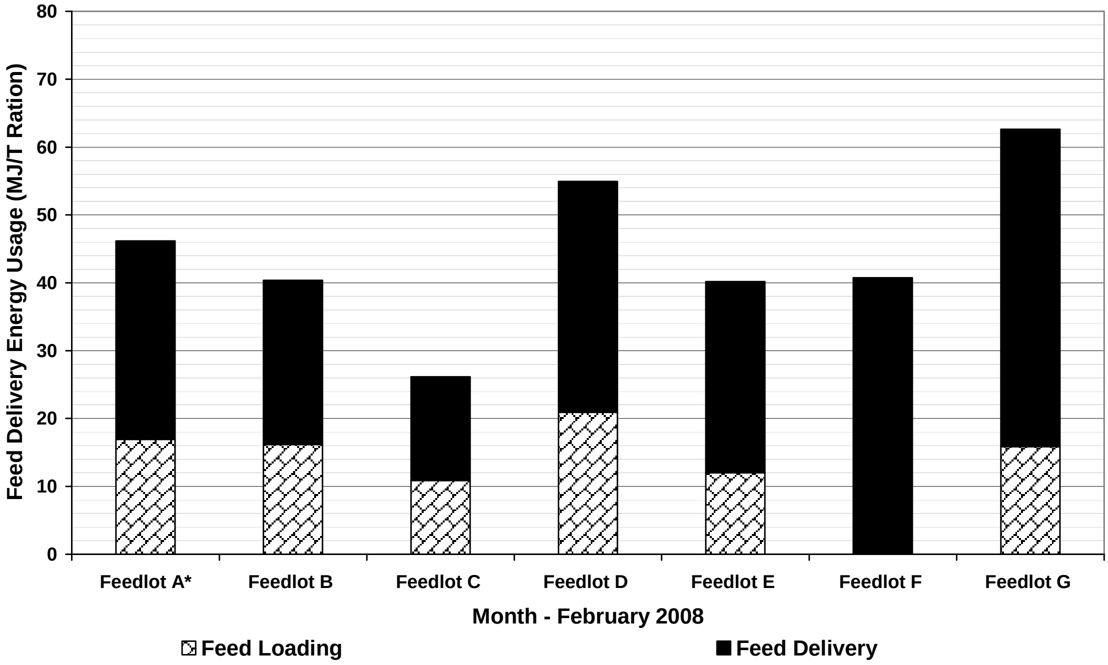


**Figure 132 – Feed delivery energy consumption for February 2008 (MJ/t ration)**

# Appendix D – Waste management energy usage

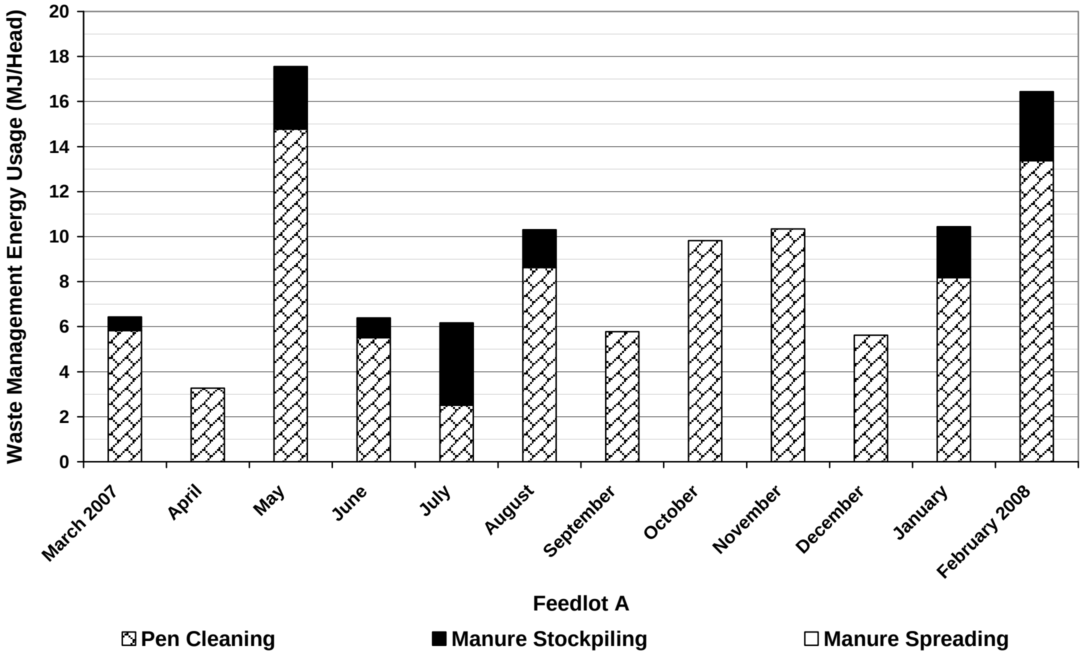


**Figure 133 – Waste management energy consumption for Feedlot A (MJ/head-on-feed/month)**

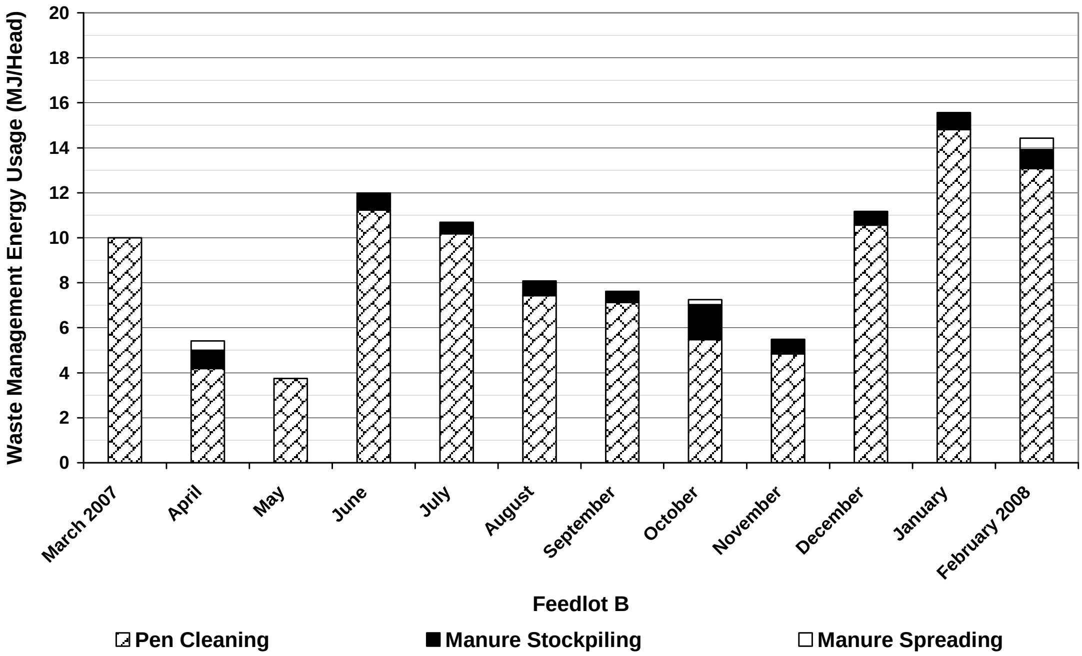


**Figure 134 – Waste management energy consumption for Feedlot B (MJ/head-on-feed/month)**

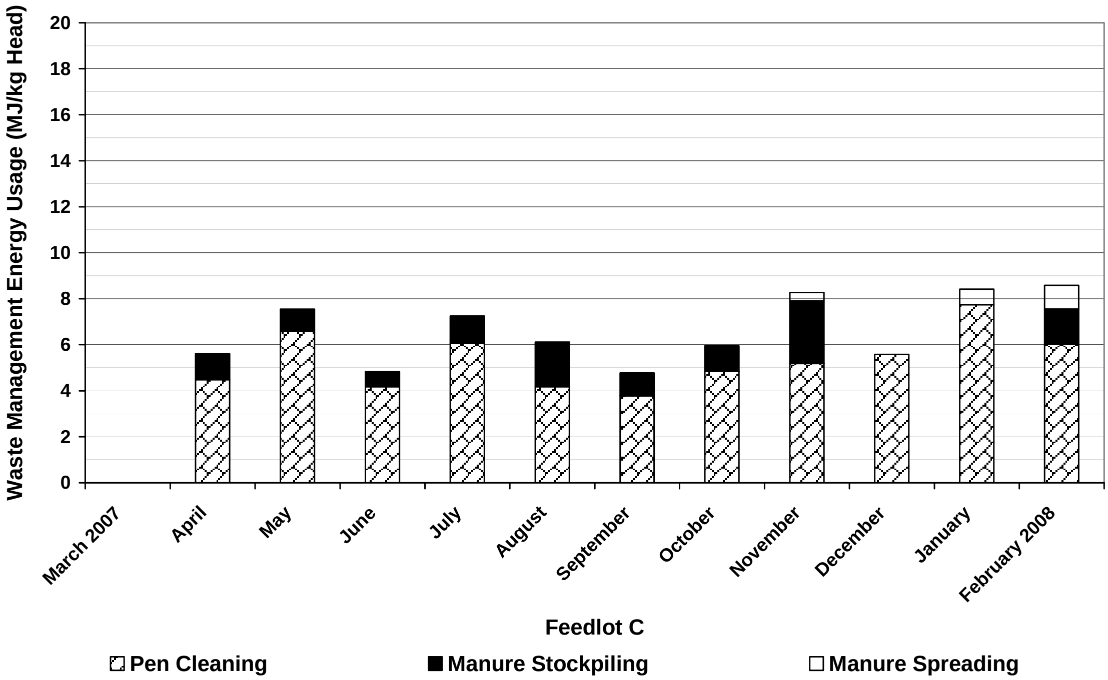


**Figure 135 – Waste management energy consumption for Feedlot C (MJ/head-on-feed/month)**

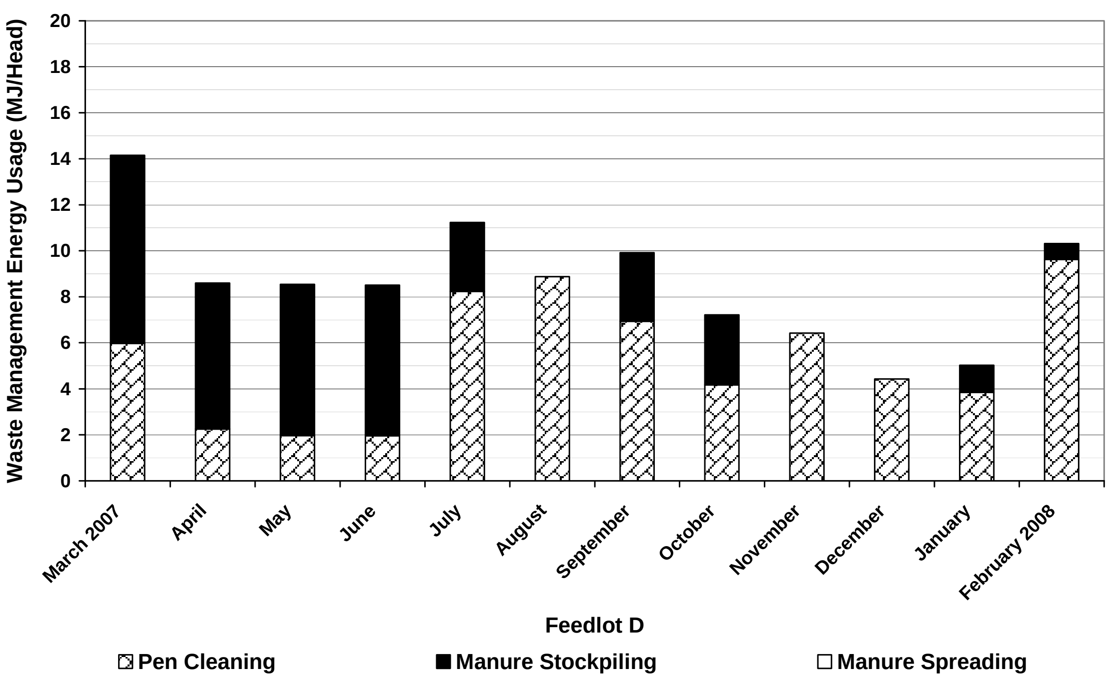


**Figure 136 – Waste management energy consumption for Feedlot D (MJ/head-on-feed/month)**

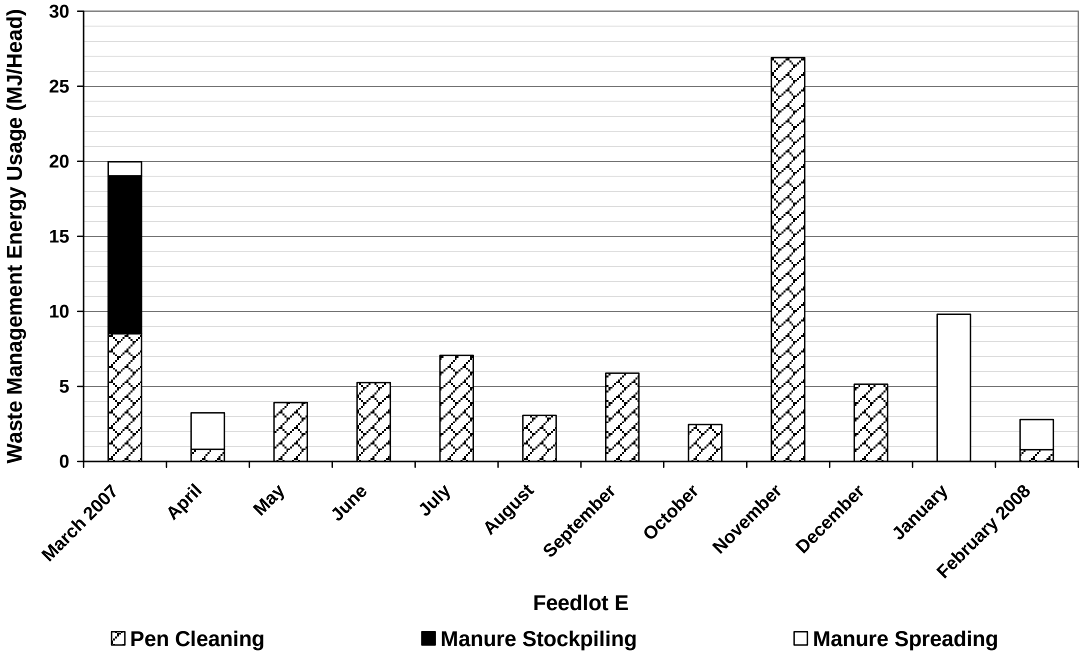


**Figure 137 – Waste management energy consumption for Feedlot E (MJ/head-on-feed/month)**

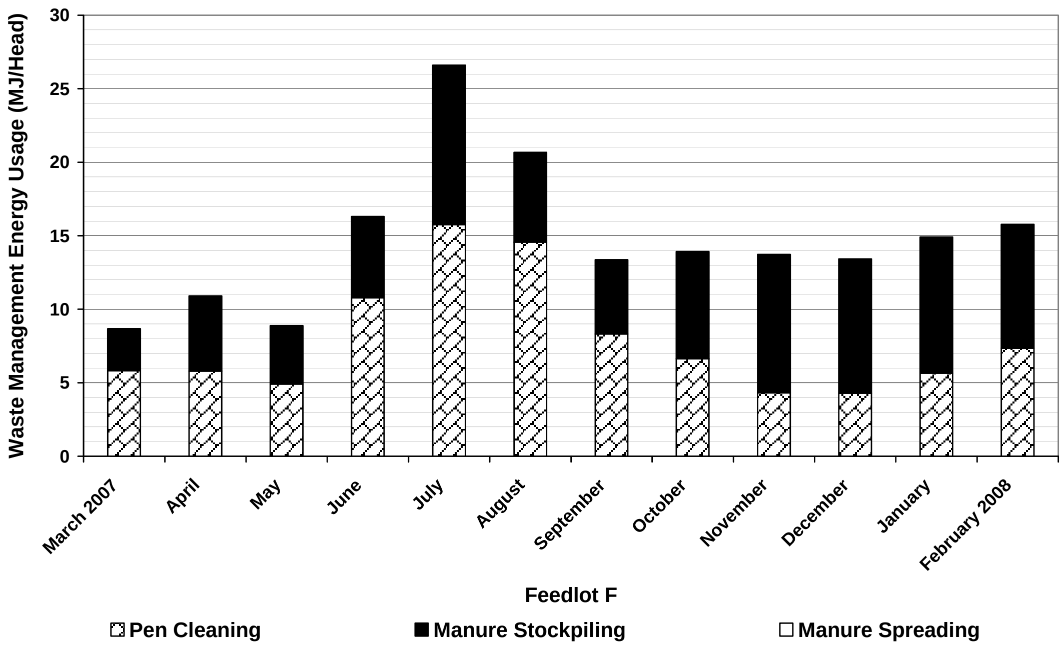


**Figure 138 – Waste management energy consumption for Feedlot F (MJ/head-on-feed/month)**

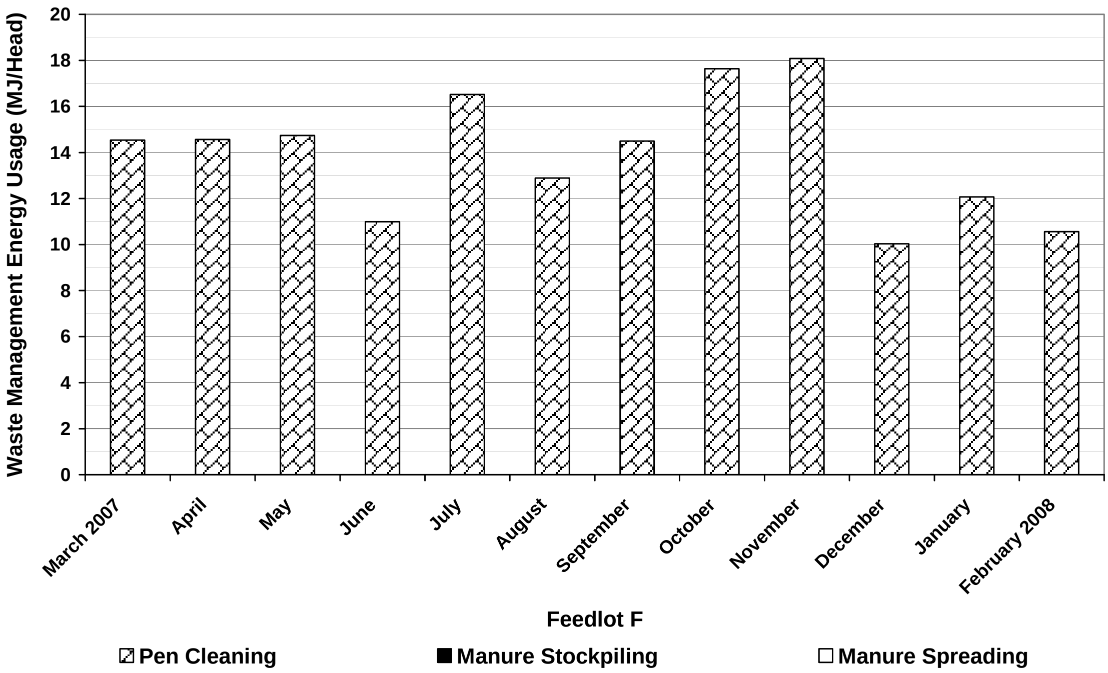


**Figure 139 – Waste management energy consumption for Feedlot G (MJ/head-on-feed/month)**

# Appendix E – Cattle washing energy usage

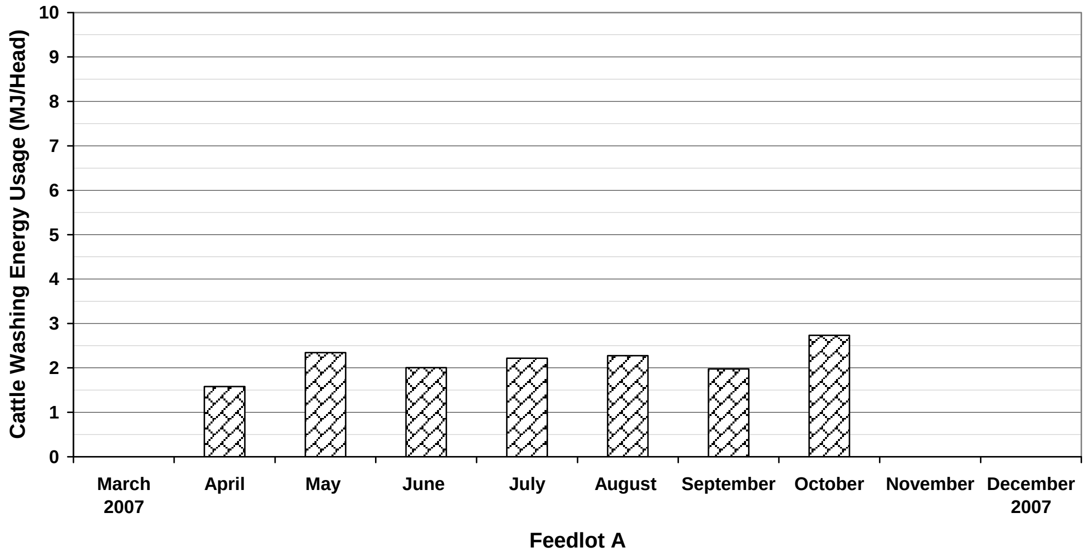


**Figure 140 – Cattle washing energy consumption for Feedlot A (MJ/head washed)**

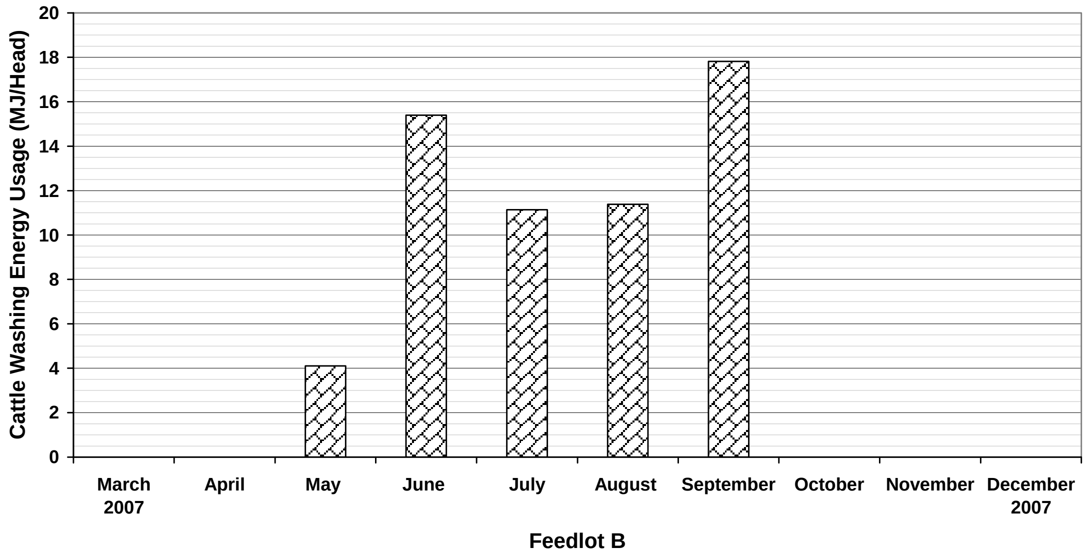


**Figure 141 – Cattle washing energy consumption for Feedlot B (MJ/head washed)**

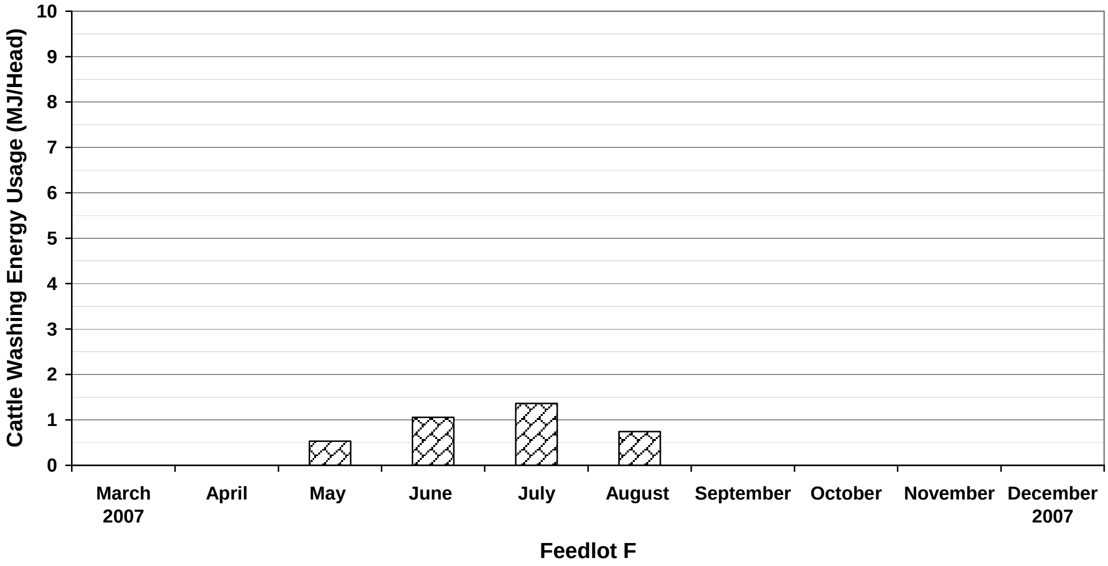


**Figure 142 – Cattle washing energy consumption for Feedlot F (MJ/head washed)**

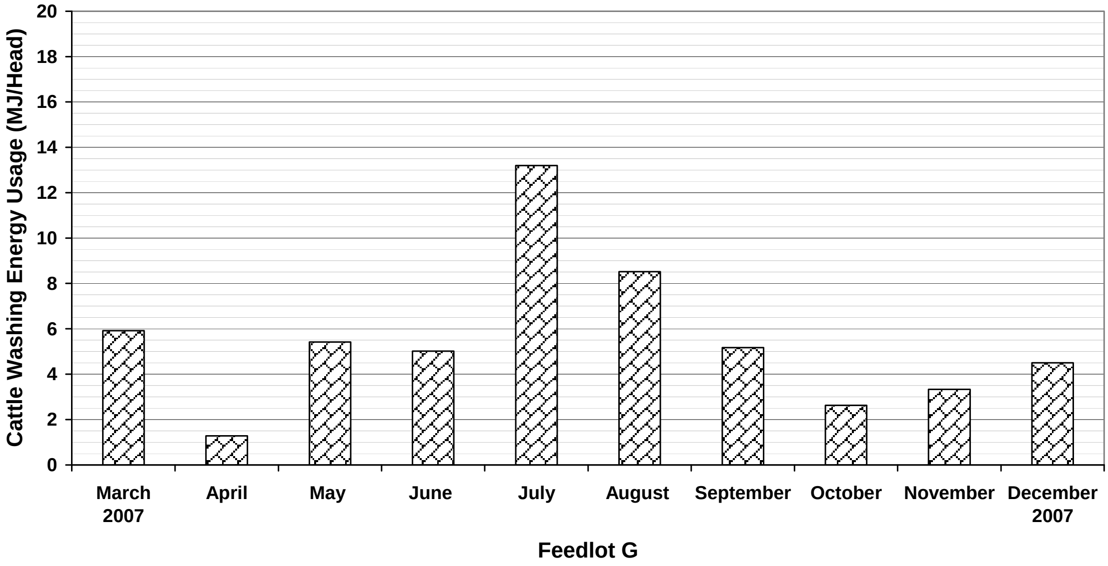


**Figure 143 – Cattle washing energy consumption for Feedlot A (MJ/head washed)**

# Appendix F - Administration and minor activities energy usage

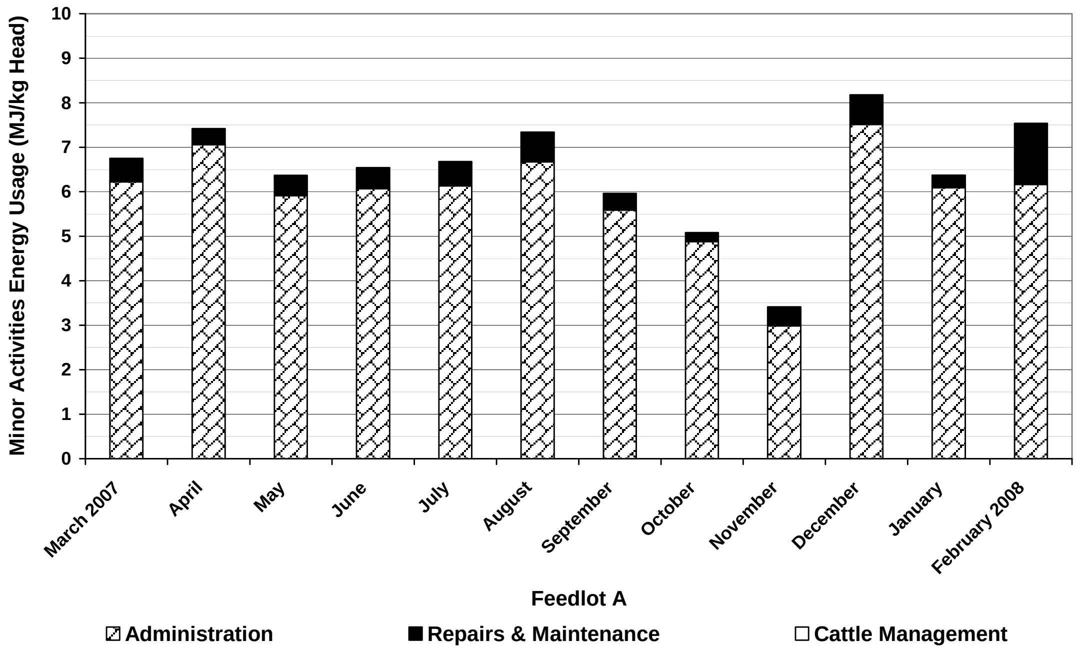


**Figure 144 – Administration and minor activities energy consumption for Feedlot A (MJ/head-on-feed/month)**

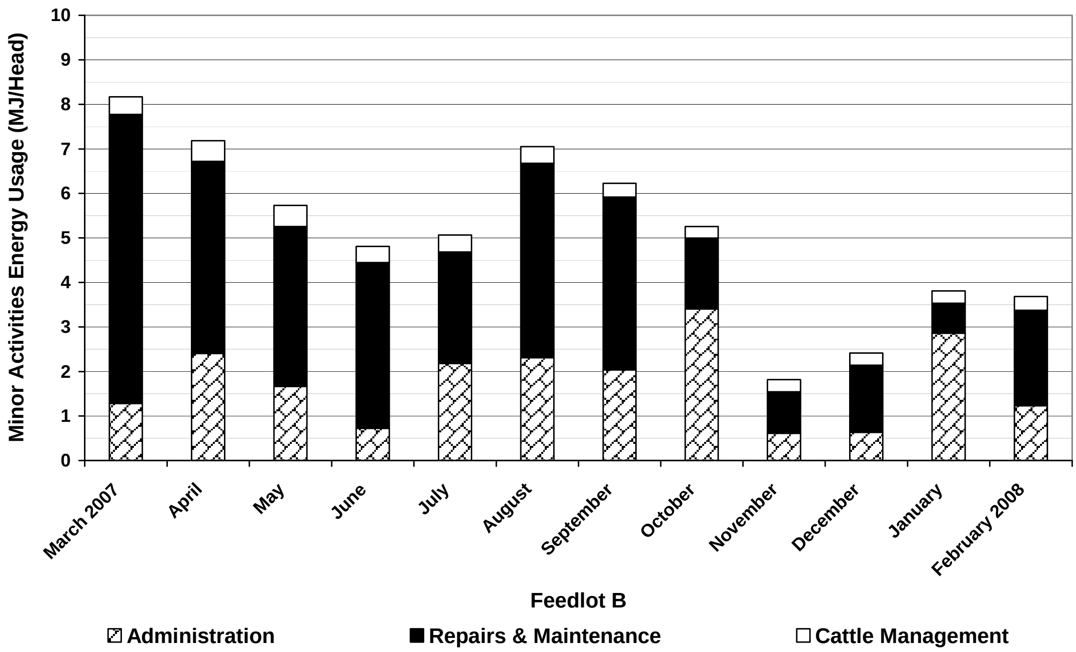


**Figure 145 – Administration and minor activities energy consumption for Feedlot B (MJ/head-on-feed/month)**

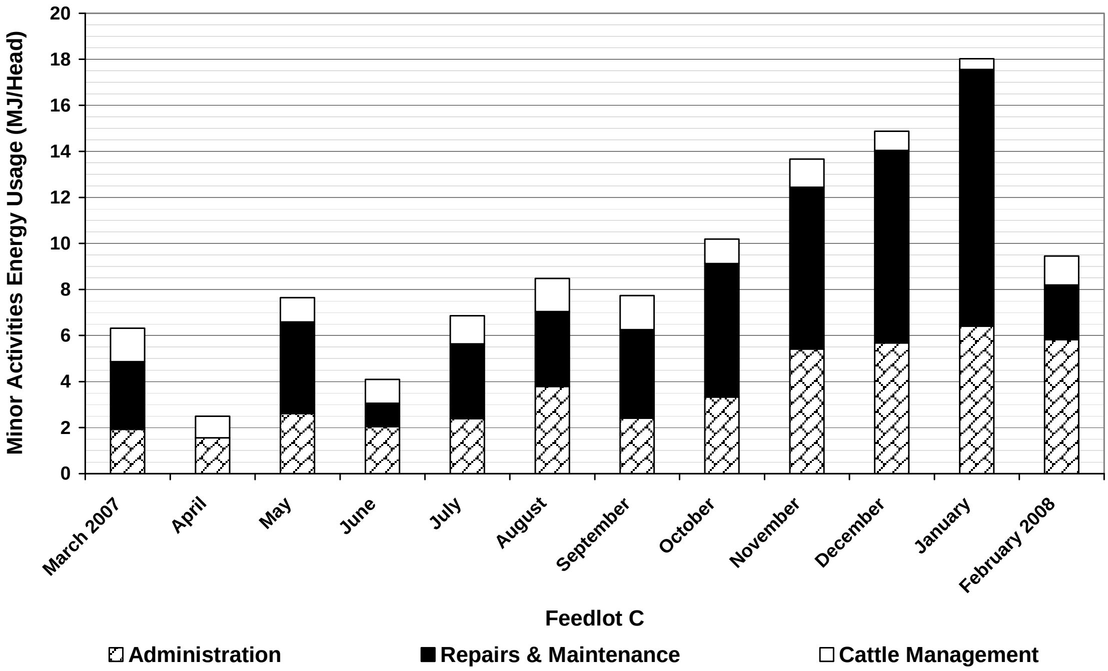


**Figure 146 – Administration and minor activities energy consumption for Feedlot C (MJ/head-on-feed/month)**

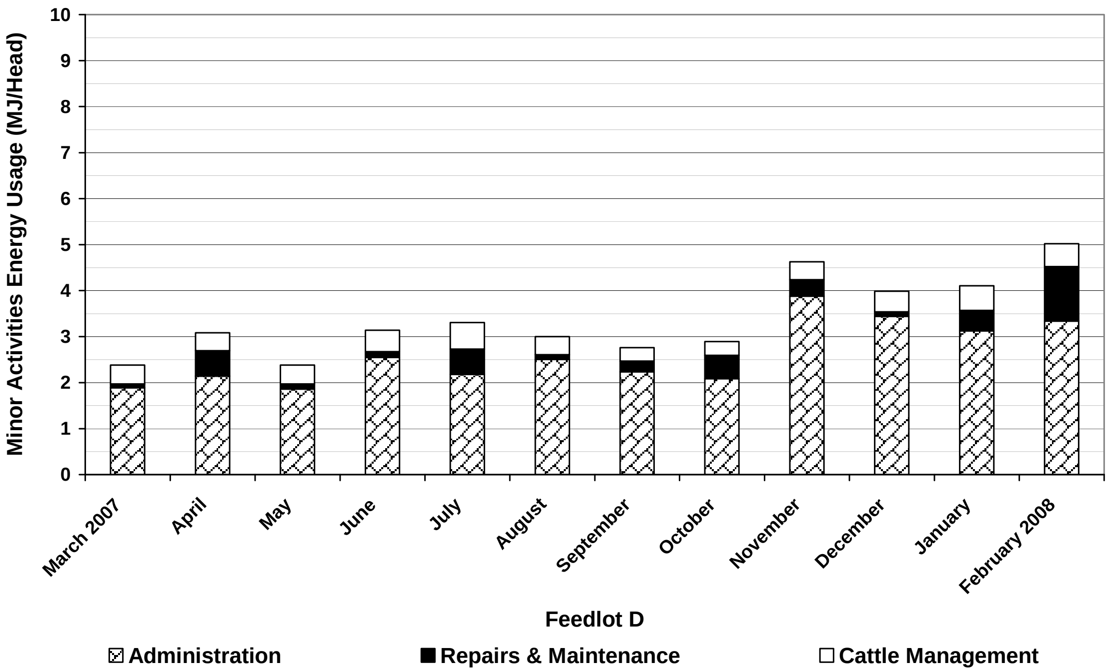


**Figure 147 – Administration and minor activities energy consumption for Feedlot D (MJ/head-on-feed/month)**

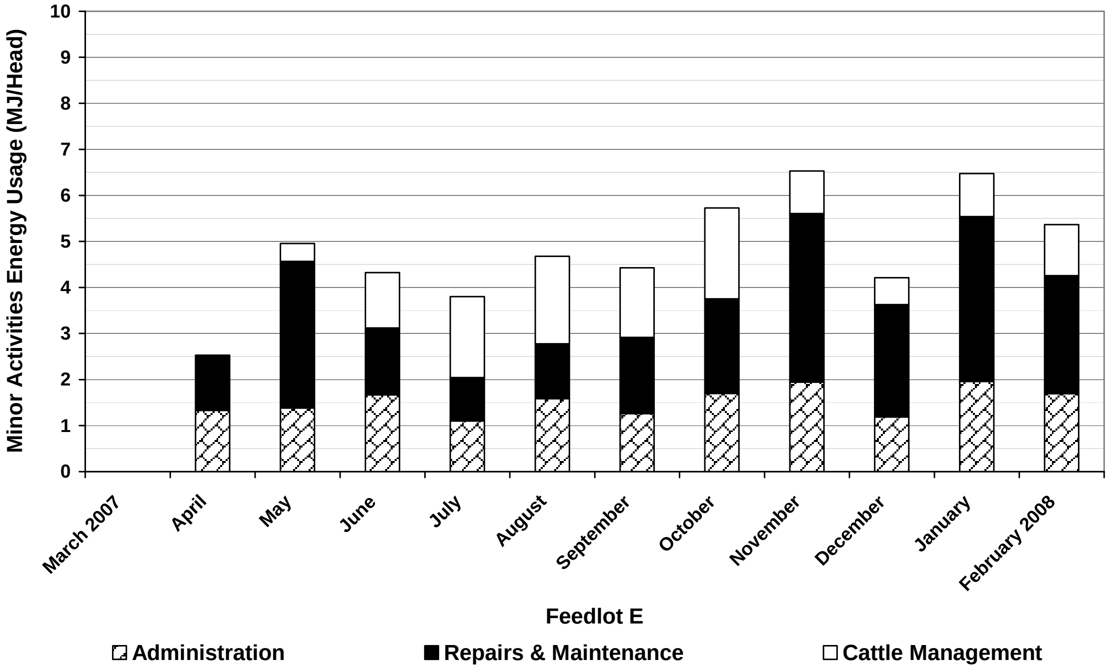


**Figure 148 – Administration and minor activities energy consumption for Feedlot E (MJ/head-on-feed/month)**

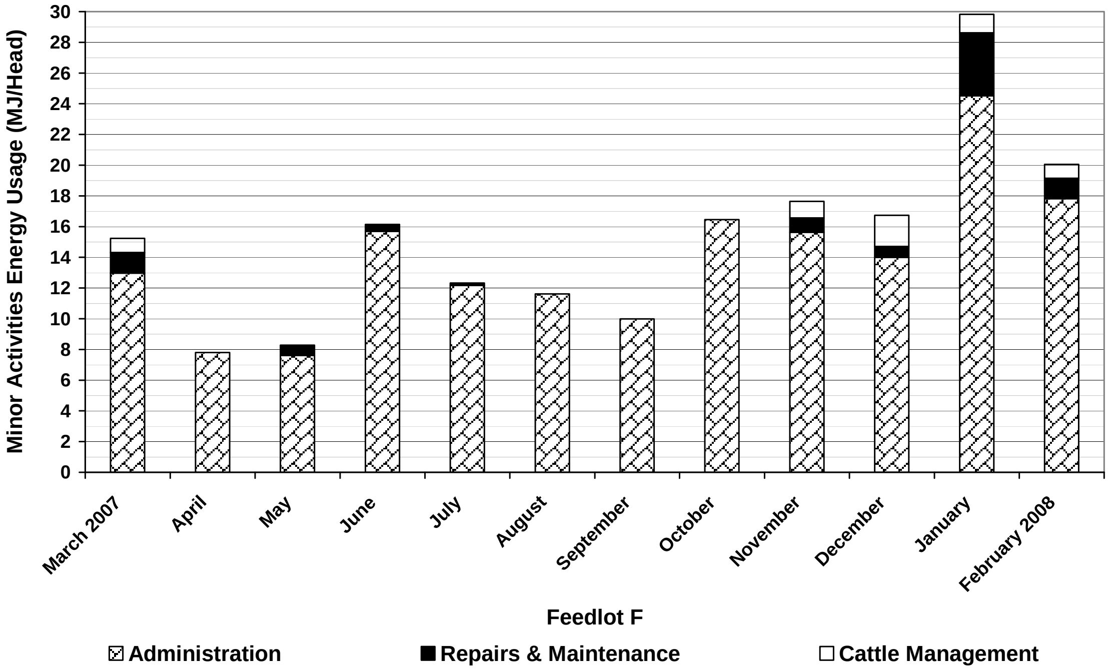


**Figure 149 – Administration and minor activities energy consumption for Feedlot F (MJ/head-on-feed/month)**

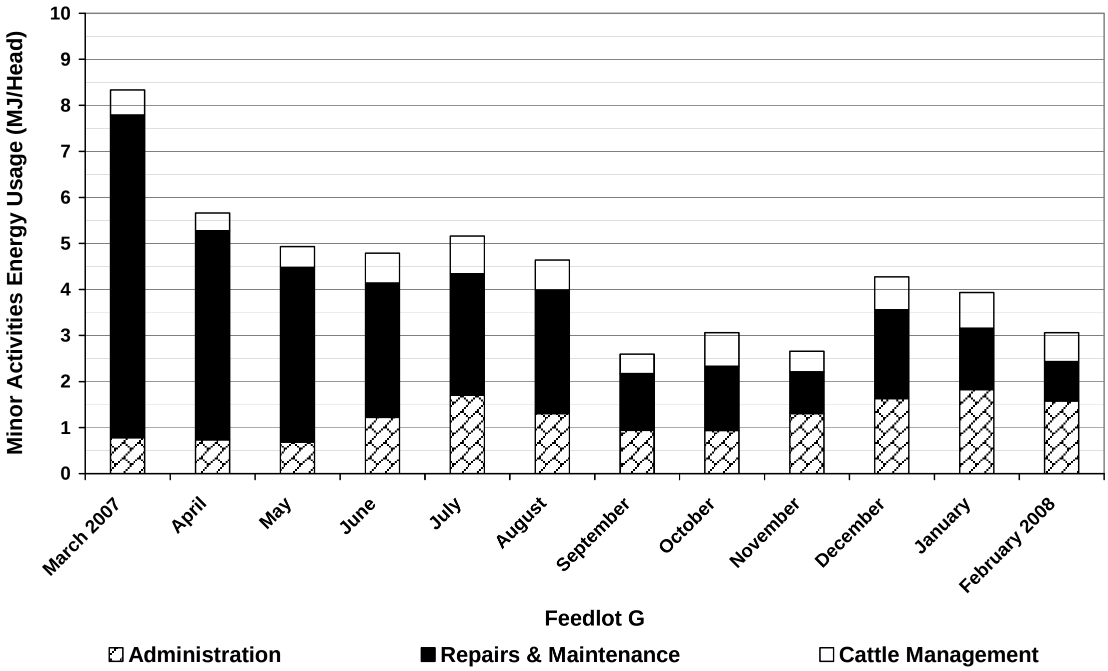


**Figure 150 – Administration and minor activities energy consumption for Feedlot G (MJ/head-on-feed/month)**