Selection For Residual Feed Intake in Beef Cattle Quantification Protocol

Public Review Version

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1.0 Project and Methodology Scope and Description

The opportunity for generating carbon offsets with this protocol arises from the direct and indirect reductions of greenhouse gas (GHG) emissions from selecting beef cattle with increased feed efficiency through the genetic merit trait known as low residual feed intake (RFI). This protocol is applicable throughout the beef cattle production chain.

This quantification protocol is written for the beef cattle managers or project developer, and familiarity with, or general understanding of beef cattle production practices is expected.

1.1 Protocol Scope and Description

This protocol quantifies emission reductions in methane emissions from calves, cows and bulls (cattle) and emissions reductions from manure handling, storage and application. **FIGURE 1.1** offers a process flow diagram for a typical project. GHG reductions (primarily methane from enteric fermentation) are due to the reduced feed intake of cattle that utilize their feed more efficiently. This also results in less manure production from low RFI cattle.

The necessary elements for implementation of this protocol are:

- The seedstock breeder will be breeding low RFI breeding animals or semen for sale. It is expected that breeding stock/semen for sale will have certified low RFI values and accuracies as part of the sale information;
- The cow-calf operator purchases the certified low RFI breeding stock and uses them in matings to produce progeny. The genetic merit of offspring from such a mating will be equivalent to half the genetic merit of the sire plus half the genetic merit of the dam. Thus each progeny is assigned an expected RFI value equal to the average or mean of the parents.
- The majority of the progeny will be sold, with accompanying paperwork to backgrounding operations or feedlots for finishing.

Protocol Approach

Residual feed intake (RFI) is a measure of feed efficiency, and it represents the amount of feed consumed, net of the animal's requirements for maintenance of body weight and production. In beef cattle, RFI is defined as ***the difference between an animal's actual feed intake and its expected feed intake based on its body size and growth over a specified period.*** The residual portion of feed intake can be used to identify animals that deviate from their expected feed intake, with efficient animals having lower (negative) RFI values.

Cattle with low RFI produce less methane from enteric fermentation and also less manure (methane and N_2O) relative to higher RFI cattle, due to that fact that they consume less feed for the same body weight and level of production. This reduction in feed intake is captured by the RFI value.

The Beef RFI Selection Protocol serves as a generic 'recipe' for project developers to follow in order to meet the applicability, measurement, monitoring, and GHG quantification requirements. There are specific requirements listed in this protocol that project developers must meet in order to qualify for project eligibility (next section). Any flexibility mechanisms allowing a deviation from the prescribed project eligibility will be stated within the Protocol Flexibility section below. The Beef RFI Selection protocol quantifies emissions reductions on the basis of the kg of dry matter feed intake per day.

Thus, the starting point for all quantification is the determination of potential sire's or replacement heifer's RFI in comparison to other similar animals or 'base year animals' under standardized test conditions. Guidelines for standardized test conditions are outlined in more detail in **Appendix C** of this protocol. In this current version of the protocol, the identification, selection and/or measurement of RFI in beef cattle is are required to adhere to the Guidelines within Appendix C and does <u>not</u> include the use of genetic markers, as the scientific validity for the use of such is in the initial assessment stages.

The baseline condition for projects applying this protocol is defined as the Dry Matter Intake (DMI) of the base year animals of similar weight grouping, class and ration. This is compared to the project condition of known genetic merit for RFI or sires with Estimated Breeding Value (EBV) for RFI and the resultant dry matter intake. **FIGURE 1.2** offers a process flow diagram for a typical baseline configuration. EBVs for RFI in the project condition must be registered with the Canadian Cattle Identification Agency (CCIA), a third party, and/or an Alberta registry, confirmed by operational records, for the purpose of this protocol.

Animals in the project condition have EBVs computed using a specified year as the base year or beginning of the project. The mean EBV of a particular trait is set to zero for all the animals born in that year or earlier. This ensures that genetic improvement relative to the animals in the baseline condition can be tracked over several years. This base year can also be used in the protocol to illustrate that practice change since that year has resulted in reductions in GHG emissions. For RFI, it is also essential that the average feed intake (DMI) of animals during the RFI test period for the base year is calculated or estimated.

The project condition is defined as using low (negative) RFI EBV sires and/or replacement heifers and encompasses pens and/or pastures where the cattle are raised and fed, the facility where manure is stored, and the land where the manure is spread. The project may include a number of sites, and a variety of enterprises, but all project farms will address the activities within the boundary of the Beef RFI Selection Protocol.

Protocol Applicability

To demonstrate that a project meets the requirements under this Quantification Protocol, the project developer must supply sufficient evidence to demonstrate that:

1. The Project Developer has had beef animals in the project condition tested for RFI at an established individual animal feed intake facility listed in **Appendix C** to achieve a certified RFI EBV, classified as Post-weaning RFI (RFI_P). These will be

measured on breeding cattle (bulls and replacement heifers) when they are 8 to 13 months of age. RFI requires the **measurement of actual individual animal feed intake over a specific time period (according to Appendix C).** Animals with certified RFI EBVs from within North America can be used so long as it can be demonstrated the EBV's are conducted within breed or genetic strain, and the registration certificates accompany the animal to Alberta.

2. If RFI EBVs have been calculated by multiplying the phenotypic RFI by the trait heritability (e.g., 40%) then minimum accuracy values for RFI is set at 60%. If RFI EBVs have been calculated using Best Linear Unbiased Predcition (BLUP) procedures then minimum accuracy for RFI EBV is set at 40%.

3. The Project Developer must identify and provide full information and documentation from the facility generating the certified EBV(s) on any RFI tested animal(s) or purchased bulls/semen with certified RFI-EBVs. This information will be needed for verification and/or auditing requirements.

4. All qualifying cattle to be included under this protocol must have ***actual birth dates*** registered with the Canadian Cattle Identification Agency (CCIA) and/or an Alberta registry, confirmed by operational records. The date of first calf born or season of calving for a group is not acceptable for the purposes of this protocol.

5. Credit duration – first generation only within Alberta's eight year crediting period. This means that ***reductions may be claimed on the animals with low RFI EBVs and their first generation progeny only.***

6. All farms in the project are currently storing manure and applying manure or custom applying manure to land as confirmed by an affirmation from the project developer.

7. The quantification of reductions achieved by the project is based on actual measurement and monitoring (exceptions where noted) as indicated by the proper application of this protocol.

8. The project must meet all other requirements for offset eligibility as specified in the applicable regulation and guidance documents for the Alberta Offset System. Of particular note:
    - The date of equipment installation, operating parameter changes or process reconfiguration are initiated or have effect on the project on or after January 1, 2002 as indicated by records;
    - Ownership and/or title to the emission reduction offsets must be established as indicated by the necessary contracting and/or records.

Protocol Flexibility

Flexibility in applying the quantification protocol is provided to project developers in three ways:

1. Projects that do not have the appropriate data for establishing Dry Matter Intake (DMI) for animals in the baseline year (‘base year animals) may use regional data by animal category, diet composition and dry matter intake (DMI) for establishment of the baseline conditions or DMI can be calculated from IPCC Tier 2, NRC (2001) and/or a ration formulation computer program like CowBytes™ (Alberta Agriculture and Rural Development) within animal category and ration (e.g., 650 to 750 lb steer calves on a backgrounding diet growing at 1.75 lb/day).
2. If one of the parents of a first generation progeny does not have its own certified RFI-EBV, its EBV can be assumed to be zero (meaning the average RFI for the progeny will be 50% of the certified RFI-EBV parent); and,
3. Site specific emission factors may be substituted for the generic emission factors indicated in this protocol document. The methodology for generation of these emission factors must ensure reasonable accuracy and verifiability.

If applicable, the project developer must indicate and justify why flexibility provisions have been used and provide sufficient justification for verification purposes.

Note: this Beef RFI Selection quantification protocol may be bundled with other approved quantification protocols that have been designed for beef cattle operations (i.e. such as Edible Oils in Cattle Feeding Regime).

FIGURE 1.1: Process Flow Diagram for Project Condition

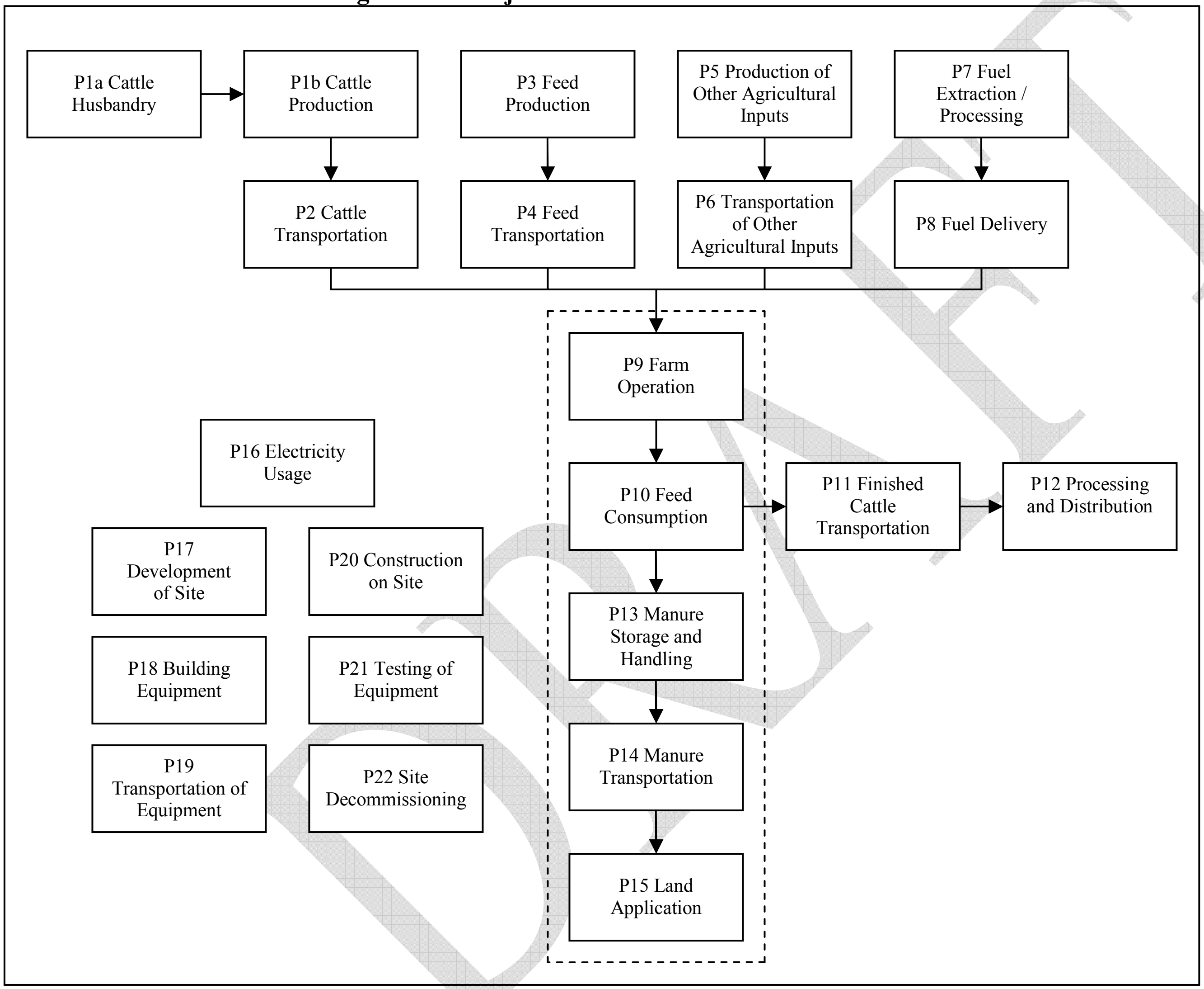
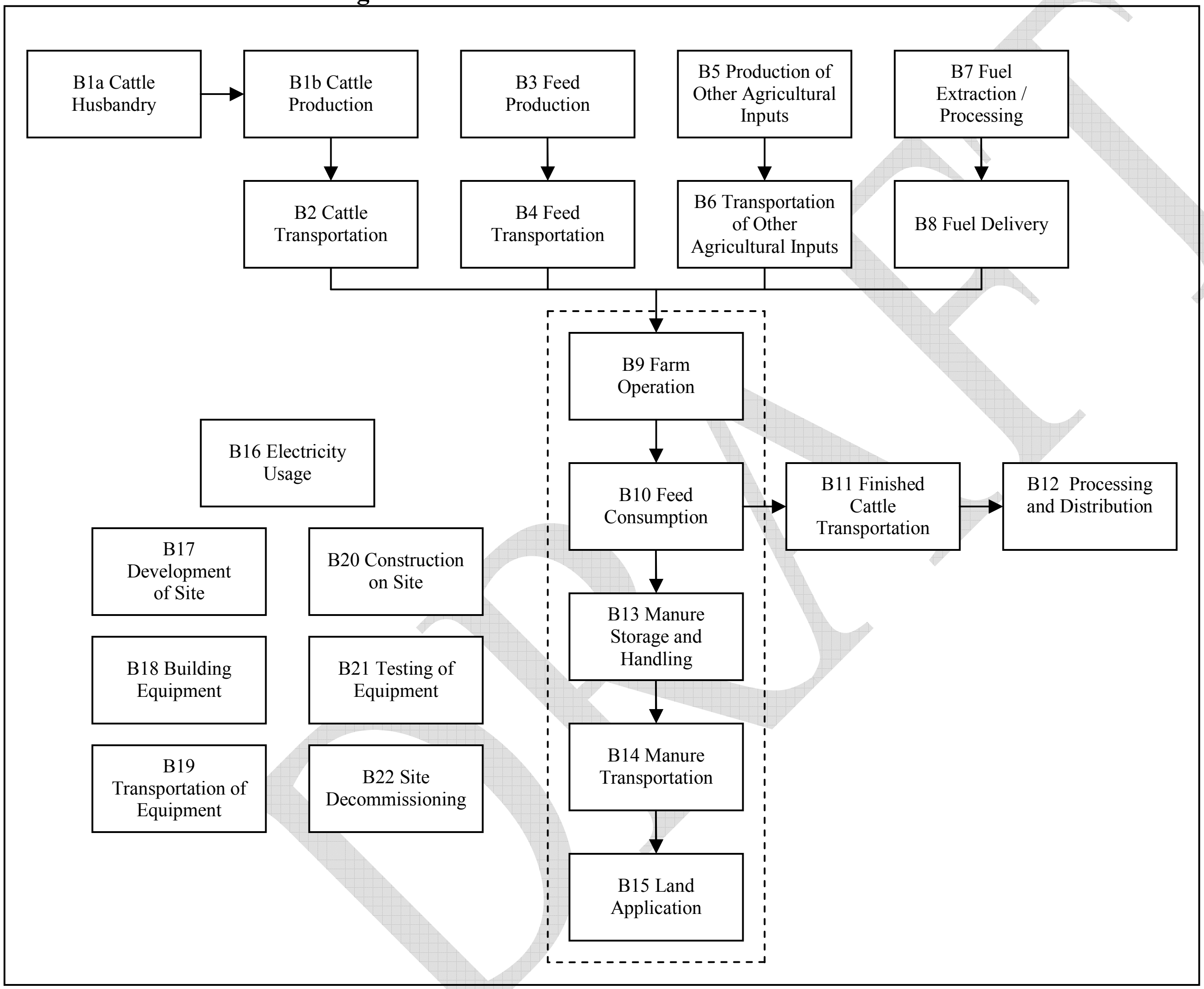


FIGURE 1.2: Process Flow Diagram for Baseline Condition



1.2 Glossary of New Terms

Accuracy (of selection)	Accuracy of estimated breeding values (EBVs) range from zero to 100 and is a measure of the strength of the relationship between true breeding value and the predicted breeding value for a trait under selection. When accuracy is high, prediction of breeding values will be good, and the breeding value is less likely to change. If RFI EBVs have not been calculated using standardized Best Linear Unbiased Prediction (BLUP) procedures then RFI EBVs can be approximated by multiplying the phenotypic RFI value by the heritability of RFI (40%). In a classical sense, the accuracy of such EBVs can be approximated as the square root of the heritability x 100 or 63%. *Thus for this protocol the minimum accuracy values for RFI EBVs is set at 60% and pertains to animals that have been measured for individual animal feed intake and growth following standard operating procedures* (Arthur et al. 2001; Basarab et al. 2003; Nkrumah et al. 2006; BIF 2009)[1].
Dry Matter Intake (DMI)	The amount of feed an animal consumes after all of the water has been removed from the wet and dry feeds.
Gross Energy Intake (GEI)	The energy content of the dry matter intake.
Enteric Emissions	Emissions of methane from the cattle as part of the digestion of feed materials.
Estimated Breeding Value (EBV)	Are predictions or estimates of an animal's genetic merit, based upon available performance information on the individual and it's relatives. EBV is a systematic way of combining available performance information on the individual and sibs and the

[1] **Basarab, J.A., Price, M.A., Aalhus, J.L., Okine, E.K., Snelling W.M., and Lyle, K.L. 2003.** Residual feed intake and body composition in young growing cattle. Can. J. Anim. Sci. **83:**189-204.
Arthur, P.F., Renand, G. and Krauss, D. 2001. Genetic and phenotypic relationships among different measures of growth and feed efficiency in young Charolais bulls. Livest. Prod. Sci. **68:**131-139.
Nkrumah, D.J., Okine, E.K., Mathison, G.W., Schnid, K., Li, C., Basarab, J.A., Price, M.A., Wang, Z. and Moore, S.S. 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. J. Anim. Sci. **84:**145-153.
Crews, D.H. Jr., Carstens, G.E., Basarab, J.A., Hill, R.A. and Nielsen, M. E. 2009. CHAPTER 7 – FEED INTAKE and EFFICIENCY. In "Beef Improvement Federation Guidelines"

	progeny of the individual. Expected progeny differences (EPDs) have replaced EBVs in most breed association programs.
Expected Progeny Difference (EPD)	The difference in expected performance of future progeny of an individual, compared with expected performance of future progeny of an individual of average genetic merit in the base time frame for the genetic evaluation. EPDs are estimated from phenotypic merit of an individual and all of its relatives and are one-half of the EBV
Functional Equivalence	The Project and the Baseline conditions should provide the same function and quality of products or services. This type of comparison requires a common metric or unit of measurement (such as the number of acres farmed) for comparison between the Project and Baseline activities. In this case, it is per kg of beef produced between baseline and project.
Land Application	The beneficial use of the manure and/or digestate applied to cropland based upon crop needs and the composition of agricultural material as a source of soil amendment and/or fertility.
Residual Feed Intake (RFI)	The difference between an animal's actual feed intake and its expected feed requirements for maintenance and production. RFI values are expressed as kg of dry matter intake (DMI) per day and are standardized to 10 MJ of metabolizable energy (ME) intake per kg of DMI. For the purposes of this protocol, all RFI values calculated for breeding animals are post-weaning RFI values or RFI_P as opposed to RFI values calculated during the finishing period (RFI-F) – the latter is not contemplated under this protocol. These values are certified by an Alberta animal testing facility (see **Appendix C**).

2.0 Quantification Development and Justification

The following sections outline the quantification development and justification.

2.1 Identification of Sources and Sinks (SS's) for the Project

SSs were identified for the project by reviewing the technical seed documents and relevant process flow diagrams, consulting with the Technical Working Group and reviewing best practice guidance as well as other relevant GHG quantification protocols. This iterative process confirmed that the SSs in the process flow diagrams covered the full scope of eligible project activities under the protocol.

The criteria for classifying the SSs, based on best practice guidance are as follows:

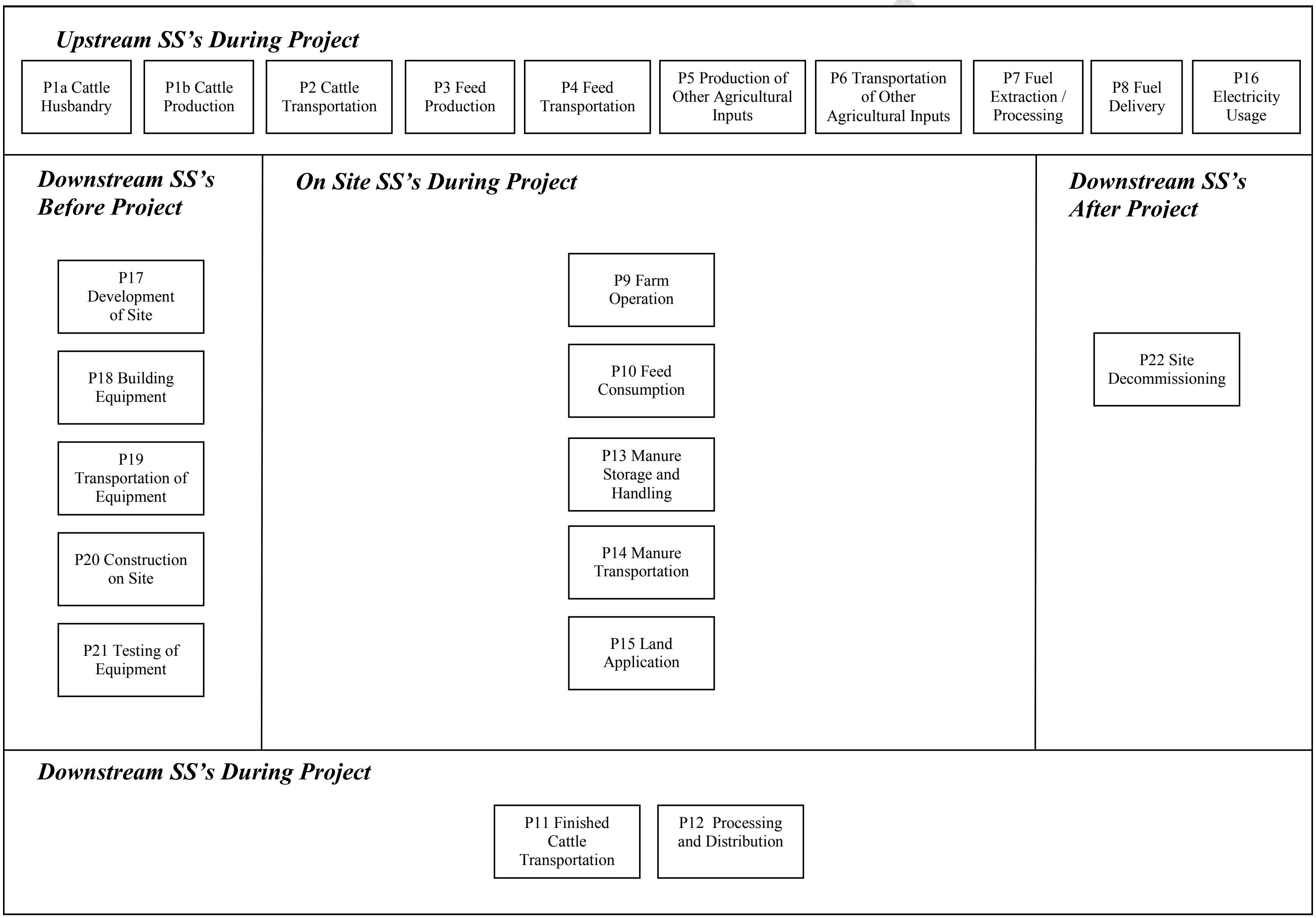
Controlled: The behaviour or operation of a controlled SS is under the direction and influence of a project developer through financial, policy, management, or other instruments.

Related: A related SS has material and / or energy flows into, out of, or within a project but is not under the reasonable control of the project developer.

Affected: An affected SS is influenced by the project activity through changes in market demand or supply for projects or services associated with the project.

Based on the process flow diagrams provided in **FIGURE 1.1**, the project SS's were organized into life cycle categories in **FIGURE 2.1**. Descriptions of each of the SS's and their classification as controlled, related or affected are provided in **TABLE 2.1.**

FIGURE 2.1: Project Element Life Cycle Chart



1 **TABLE 2.1: Project SS's**

1. SS	2. Description	3. Controlled, Related or Affected
Upstream SS's during Project Operation		
P1a Cattle Husbandry	Cattle husbandry may include insemination and all other practices prior to the birth of the calf. Quantities and types for each of the energy inputs would be contemplated to evaluate functional equivalence with the baseline condition.	Related
P1b Cattle Production	Cattle production may include raising calves, including time in pasture, that are input to the enterprise. Feed consumption includes the enteric emissions from the cattle and related manure production. The feed composition would need to be tracked to ensure functional equivalence with the baseline condition. Length of each type of feeding cycle would need to be tracked.	Related
P2 Cattle Transportation	Cattle may be transported to the project site by truck, barge and/or train. The related energy inputs for fuelling this equipment are captured under this SS, for the purposes of calculating the resulting greenhouse gas emissions. Type of equipment, number of loads and distance travelled would be used to evaluate functional equivalence with the baseline condition.	Related
P3 Feed Production	Feed may be produced from agricultural materials and amendments. The processing of the feed may include a number of chemical and mechanical amendment processes. This requires several energy inputs such as natural gas, diesel and electricity. Quantities and types for each of the energy inputs would be tracked to evaluate functional equivalence with the baseline condition.	Related
P4 Feed Transportation	Feed may be transported to the project site by truck, barge and/or train. The related energy inputs for fuelling this equipment are captured under this SS, for the purposes of calculating the resulting greenhouse gas emissions. Type of equipment, number of loads and distance travelled would be used to evaluate functional equivalence with the baseline condition.	Related
P5 Production of Other Agricultural Inputs	Other agricultural inputs, such as feed supplements, bedding, etc., may be produced from agricultural materials and amendments. The processing of these inputs may include a number of chemical, mechanical and amendment processes. This requires several energy inputs such as natural gas, diesel and electricity. Quantities and types for each of the energy inputs would be tracked to evaluate functional equivalence with the baseline condition.	Related
P6 Transportation of Other Agricultural Inputs	Feed may be transported to the project site by truck, barge and/or train. The related energy inputs for fuelling this equipment are captured under this SS, for the purposes of calculating the resulting greenhouse gas emissions. Type of equipment, number of loads and distance travelled would be used to evaluate functional equivalence with the baseline condition.	Related

P7 Fuel Extraction and Processing	Each of the fuels used throughout the on-site component of the project will need to be sourced and processed. This will allow for the calculation of the greenhouse gas emissions from the various processes involved in the production, refinement and storage of the fuels. The total volumes of fuel for each of the on-site SS's are considered under this SS. Volumes and types of fuels are the important characteristics to be tracked.	Related
P8 Fuel Delivery	Each of the fuels used throughout the on-site component of the project will need to be transported to the site. This may include shipments by tanker or by pipeline, resulting in the emissions of greenhouse gases. It is reasonable to exclude fuel sourced by taking equipment to an existing commercial fuelling station as the fuel used to take the equipment to the site is captured under other SS's and there is no other delivery.	Related
P16 Electricity Usage	Electricity may be required for operating the facility. This power may be sourced either from internal generation, connected facilities or the local electricity grid. Metering of electricity may be netted in terms of the power going to and from the grid. Quantity and source of power are the important characteristics to be tracked as they directly relate to the quantity of greenhouse gas emissions.	Related
Onsite SS's during Project Operation		
P9 Farm Operation	Greenhouse gas emissions may occur that are associated with the operation and maintenance of the facility operations. This may include running vehicles and facilities at the project site for the distribution of the various inputs. Quantities and types for each of the energy inputs would be tracked.	Controlled
P10 Feed Consumption	Feed consumption includes greenhouse gas sources from enteric fermentation and related manure production. The feed composition for various lots or groupings of animals on various rations would need to be tracked in both baseline and project to ensure functional equivalence.	Controlled
P13 Manure Storage and Handling	Greenhouse gas emissions can result from the operation of manure storage and handling facilities. This will include emissions from energy use, and from the emissions of methane and nitrous oxide from the manure being stored and processed. Quantities and types for each of the energy inputs would be tracked. Quantities, duration and conditions would also need to be tracked.	Controlled
P14 Manure Transportation	Manure may need to be transported to the field for land application from storage. Transportation equipment would be fuelled by diesel, gas or natural gas. Quantities for each of the energy inputs would be contemplated to evaluate functional equivalence with the baseline condition.	Controlled
P15 Land Application	Manure may then be land applied. This may require the use of heavy equipment and mechanical systems. This equipment would be fuelled by diesel, gas, or natural gas resulting in greenhouse gas emissions. Other fuels may also be used in some rare cases. Quantities for each of the energy inputs would be contemplated to evaluate functional equivalence with the baseline condition.	Controlled
Downstream SS's during Project Operation		

P11 Finished Cattle Transportation	Finished cattle may be transported from the project site by truck, barge and/or train. The related energy inputs for fuelling this equipment are captured under this SS, for the purposes of calculating the resulting greenhouse gas emissions. Type of equipment, number of loads and distance travelled would need to be tracked.	Related
P12 Processing and Distribution	Greenhouse gas emissions may occur that are associated with the processing and distribution components downstream of the cattle finishing facility operations. This may include running vehicles and facilities at other sites. Quantities and types for each of the energy inputs would be tracked.	Related
Other		
P17 Development of Site	The site of the facility may need to be developed. This could include civil infrastructure such as access to electricity, gas and water supply, as well as sewer etc. This may also include clearing, grading, building access roads, etc. There will also need to be some building of structures for the facility such as storage areas, storm water drainage, offices, vent stacks, firefighting water storage lagoons, etc., as well as structures to enclose, support and house the equipment. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels and electricity used to power equipment required to develop the site such as graders, backhoes, trenching machines, etc.	Related
P18 Building Equipment	Equipment may need to be built either on-site or off-site. This includes all of the components of the storage, handling, processing, combustion, air quality control, system control and safety systems. These may be sourced as pre-made standard equipment or custom built to specification. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels and electricity used to power equipment for the extraction of the raw materials, processing, fabricating and assembly.	Related
P19 Transportation of Equipment	Equipment built off-site and the materials to build equipment on-site, will all need to be delivered to the site. Transportation may be completed by truck, barge and/or train. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels to power the equipment delivering the equipment to the site.	Related
P20 Construction on Site	The process of construction at the site will require a variety of heavy equipment, smaller power tools, cranes and generators. The operation of this equipment will have associated greenhouse gas emission from the use of fossil fuels and electricity.	Related
P21 Testing of Equipment	Equipment may need to be tested to ensure that it is operational. This may result in running the equipment using fossil fuels in order to ensure that the equipment runs properly. These activities will result in greenhouse gas emissions associated with the combustion of fossil fuels and the use of electricity.	Related
P22 Site Decommissioning	Once the facility is no longer operational, the site may need to be decommissioned. This may involve the disassembly of the equipment, demolition of on-site structures, disposal of some materials, environmental restoration, re-grading, planting or seeding, and transportation of materials off-site. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels and electricity used to power equipment required to decommission the site.	Related

2.2 Baseline Scenario

2.2.1. Identification and Assessment of Possible Baseline Scenarios

An assessment of potential baseline scenarios was conducted based on the recommended methodology from best practice guidance in the Alberta Offset Credit Project Guidance Document (February 2008). Potential baseline options were assessed based on their capacity to incorporate the project developer's historical cattle feed intake prior to selection and measurement for low residual feed intake animals (e.g. the 'business as usual' practice). Each baseline scenario also contemplated the selection of a static or dynamic approach. **TABLE 2.2**, below provides a summary of the different baseline scenarios considered.

TABLE 2.2: Assessment of Possible Baseline Scenarios

1. Baseline Options	2. Description	3. Static / Dynamic Baseline	4. Accept or Reject and Justify
Performance Standard	Assessment of baseline scenario based on the assessment of a typical Dry Matter Feed Intake of cattle based on best practice guidance.	Static.	Accept as alternate scenario to historical based. Standardized programs like Cowbytes or NRC databases can be used to estimate Dry Matter Intake for Base Year Animals of a similar ration and weight class as the Project Condition animals.
Projection Based	Projection of the baseline scenario based on modeling the future reductions of GHG emissions due to low residual feed intake selection within herds.	Dynamic.	Reject. Actual RFI-EBV testing is required for Baseline to Project conditions and efficacy in selecting for low RFI animals.
Normalized Baseline	Assessment of avoided emissions from current practice levels of reduced feed intake from low RFI cattle.	Dynamic	Reject. RFI Selection methods are new and additional – very little market penetration. No normalized baseline approach is required.
Historic Benchmark	Assessment of the baseline scenario based on verifiable records of number of animals and feed intake on farms prior to project implementation.	Static.	Accept. Based on actual farm records of Dry Matter Intake per groups of animals on similar rations and weight classes.

1. Baseline Options	2. Description	3. Static / Dynamic Baseline	4. Accept or Reject and Justify
Comparison Based	Assessment of baseline scenario based on the actual measurement of emissions from a control group of animals to be compared with the project group.	Static.	Reject. Emissions measurement impractical on herd sizes contemplated under this protocol. Measurement based on research methods and not commercially available.

2.3 Selection and Justification of Baseline Scenario

The baseline condition for this protocol is defined as the GHG emissions from a grouping of animals as a result of normal dry matter intake (DMI) of feed prior to the selection for low RFI (i.e. DMI of base year animals of similar weight classes on similar rations). The baseline GHG emissions are quantified based on the business as usual efficiency of the cattle in the baseline year.

The baseline condition assesses the average feed intake for specific categories of animals on specific diets (e.g., 650-750 lb steers on a backgrounding diet growing at 1.75 lb/day). The average is based on <u>two to three lots or groups</u> of animals for <u>one year prior</u> to the project implementation. Various types of records may be used to develop the baseline including, but not limited to, animal category (e.g., replacement heifer on pasture; yearling steers on a finishing diet), average group weight of animals, approximate age (e.g., 6-7 month old steers calves, 11-12 month old yearling heifers), diet ingredient composition, and dry matter, energy and crude protein content of ration.

The project and baseline are compared, with the common metric used to demonstrate emission reductions from the selection of low RFI beef cattle being the kg of DMI per day, for specific categories of animals on specific rations. The GHG emissions per kilogram of beef in the project condition is compared to the baseline condition of an inefficient herd of animals – thus providing functional equivalence to the protocol.

2.4 Identification of SSs for the Baseline

Based on the process flow diagrams provided in **FIGURE 1.2**, the baseline SS's were organized into life cycle categories in **FIGURE 2.2**. Descriptions of each of the SS's and their classification as either 'controlled', 'related' or 'affected' is provided in **TABLE 2.3.**

The approach to quantifying the baseline will be primarily historical-based with farm level data. The baseline scenario for this protocol is static as the emissions profile for the base year animals would be compared to the slow turnover of the cattle herd to more efficient animals over time.

FIGURE 2.2: Baseline Element Life Cycle Chart

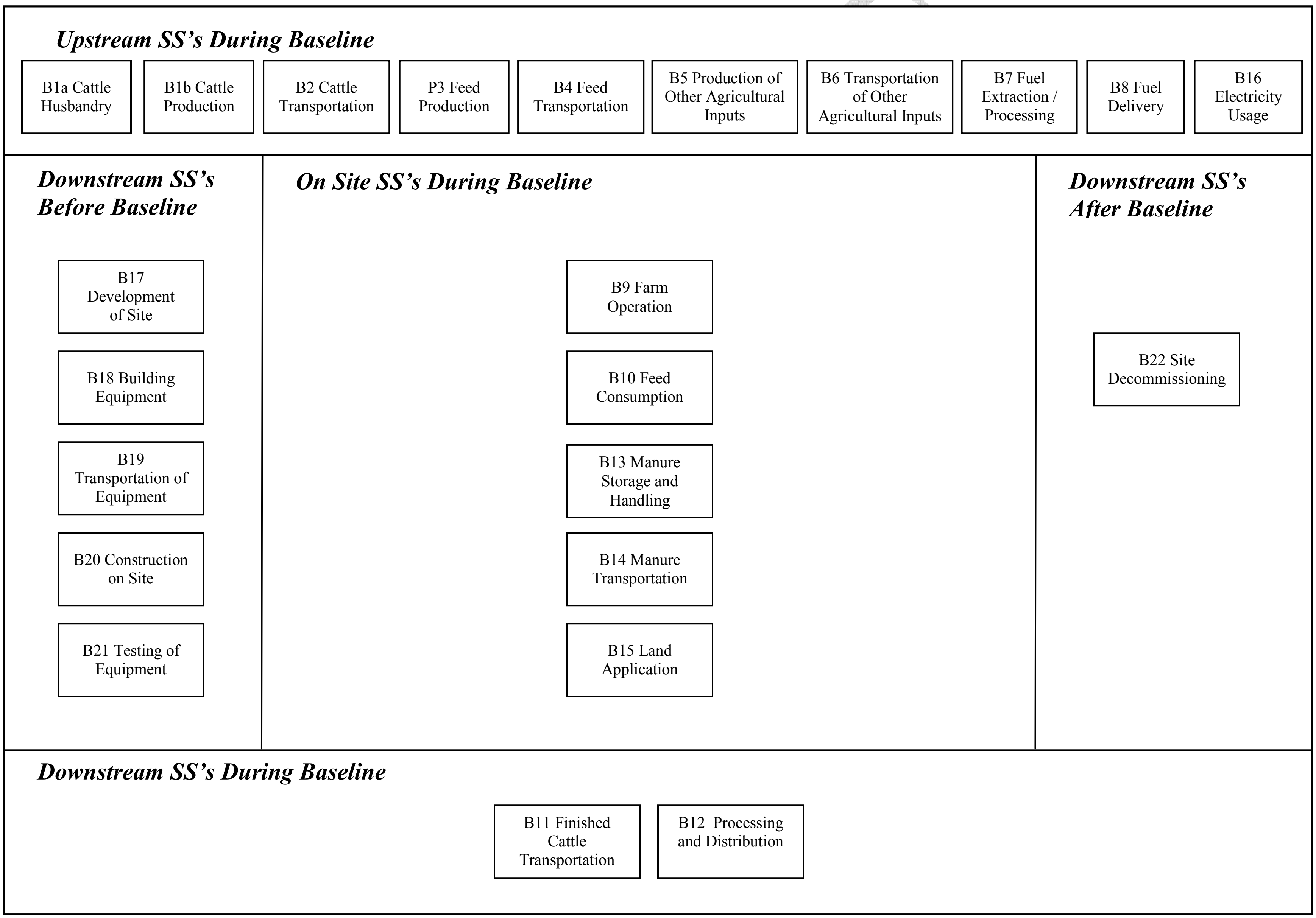


TABLE 2.3: Baseline SS's

1. SS	2. Description	3. Controlled, Related or Affected
Upstream SS's during Baseline Operation		
B1a Cattle Husbandry	Cattle husbandry may include insemination and all other practices prior to the birth of the calf. Quantities and types for each of the energy inputs would be contemplated to evaluate functional equivalence with the project condition.	Related
B1b Cattle Production	Cattle production may include raising calves, including time in pasture, that are input to the enterprise. Feed consumption includes the enteric emissions from the cattle and related manure production. The feed composition would need to be tracked to ensure functional equivalence with the project condition. Length of each type of feeding cycle would need to be tracked.	Related
B2 Cattle Transportation	Cattle may be transported to the project site by truck, barge and/or train. The related energy inputs for fuelling this equipment are captured under this SS, for the purposes of calculating the resulting greenhouse gas emissions. Type of equipment, number of loads and distance travelled would be used to evaluate functional equivalence with the project condition.	Related
B3 Feed Production	Feed may be produced from agricultural materials and amendments. The processing of the feed may include a number of chemical, mechanical and amendment processes. This requires several energy inputs such as natural gas, diesel and electricity. Quantities and types for each of the energy inputs would be contemplated to evaluate functional equivalence with the project condition.	Related
B4 Feed Transportation	Feed may be transported to the project site by truck, barge and/or train. The related energy inputs for fuelling this equipment are captured under this SS, for the purposes of calculating the resulting greenhouse gas emissions. Type of equipment, number of loads and distance travelled would be used to evaluate functional equivalence with the project condition.	Related
B5 Production of Other Agricultural Inputs	Other agricultural inputs, such as feed supplements, bedding, etc., may be produced from agricultural materials and amendments. The processing of the feed may include a number of chemical, mechanical and amendment processes. This requires several energy inputs such as natural gas, diesel and electricity. Quantities and types for each of the energy inputs would be contemplated to evaluate functional equivalence with the project condition.	Related
B6 Transportation of Other Agricultural Inputs	Feed may be transported to the project site by truck, barge and/or train. The related energy inputs for fuelling this equipment are captured under this SS, for the purposes of calculating the resulting greenhouse gas emissions. Type of equipment, number of loads and distance travelled would be used to evaluate functional equivalence with the project condition.	Related
B7 Fuel Extraction and Processing	Each of the fuels used throughout the on-site component of the project will need to be sourced and processed. This will allow for the calculation of the greenhouse gas emissions from the various processes involved in the production, refinement and storage of the fuels. The total volumes of fuel for each of the on-site SS's are considered under this SS. Volumes and types of fuels are the important characteristics to be tracked.	Related

B8 Fuel Delivery	Each of the fuels used throughout the on-site component of the project will need to be transported to the site. This may include shipments by tanker or by pipeline, resulting in the emissions of greenhouse gases. It is reasonable to exclude fuel sourced by taking equipment to an existing commercial fuelling station as the fuel used to take the equipment to the site is captured under other SS's and there is no other delivery.	Related
B16 Electricity Usage	Electricity may be required for operating the facility. This power may be sourced either from internal generation, connected facilities or the local electricity grid. Metering of electricity may be netted in terms of the power going to and from the grid. Quantity and source of power are the important characteristics to be tracked as they directly relate to the quantity of greenhouse gas emissions.	Related
Onsite SS's during Project Operation		
B9 Farm Operation	Greenhouse gas emissions may occur that are associated with the operation and maintenance of the beef production facility operations. This may include running vehicles and facilities at the project site for the distribution of the various inputs. Quantities and types for each of the energy inputs would be tracked.	Controlled
B10 Feed Consumption	Feed consumption includes GHG sources from enteric fermentation and related manure production. The feed composition for various lots or groupings of animals on various rations would need to be tracked in both baseline and project to ensure functional equivalence.	Controlled
B13 Manure Storage and Handling	Greenhouse gas emissions can result from the operation of manure storage and handling facilities. This will include emissions from energy use, and from the emissions of methane and nitrous oxide from the manure being stored and processed. Quantities and types for each of the energy inputs would be tracked. Quantities, duration and conditions would also need to be tracked.	Controlled
B14 Manure Transportation	Manure may need to be transported to the field for land application from storage. Transportation equipment would be fuelled by diesel, gas or natural gas. Quantities for each of the energy inputs would be tracked to evaluate functional equivalence with the project condition.	Controlled
B15 Land Application	Manure may then be land applied. This may require the use of heavy equipment and mechanical systems. This equipment would be fuelled by diesel, gas, or natural gas resulting in GHG emissions. Other fuels may also be used in some rare cases. Quantities for each of the energy inputs would be tracked to evaluate functional equivalence with the project condition.	Controlled
Downstream SS's during Project Operation		
B11 Finished Cattle Transportation	Finished cattle may be transported from the project site by truck, barge and/or train. The related energy inputs for fuelling this equipment are captured under this SS, for the purposes of calculating the resulting greenhouse gas emissions. Type of equipment, number of loads and distance travelled would need to be tracked.	Related
B12 Processing and Distribution	Greenhouse gas emissions may occur that are associated with the processing and distribution components downstream of the cattle finishing facility operations. This may include running vehicles and facilities at other sites. Quantities and types for each of the energy inputs would be tracked.	Related

Other		
B17 Development of Site	The site of the facility may need to be developed. This could include civil infrastructure such as access to electricity, gas and water supply, as well as sewer etc. This may also include clearing, grading, building access roads, etc. There will also need to be some building of structures for the facility such as storage areas, storm water drainage, offices, vent stacks, firefighting water storage lagoons, etc., as well as structures to enclose, support and house the equipment. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels and electricity used to power equipment required to develop the site such as graders, backhoes, trenching machines, etc.	Related
B18 Building Equipment	Equipment may need to be built either on-site or off-site. This includes all of the components of the storage, handling, processing, combustion, air quality control, system control and safety systems. These may be sourced as pre-made standard equipment or custom built to specification. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels and electricity used to power equipment for the extraction of the raw materials, processing, fabricating and assembly.	Related
B19 Transportation of Equipment	Equipment built off-site and the materials to build equipment on-site, will all need to be delivered to the site. Transportation may be completed by train, truck, by some combination, or even by courier. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels to power the equipment delivering the equipment to the site.	Related
B20 Construction on Site	The process of construction at the site will require a variety of heavy equipment, smaller power tools, cranes and generators. The operation of this equipment will have associated greenhouse gas emission from the use of fossil fuels and electricity.	Related
B21 Testing of Equipment	Equipment may need to be tested to ensure that it is operational. This may result in running the equipment using fossil fuels in order to ensure that the equipment runs properly. These activities will result in greenhouse gas emissions associated with the combustion of fossil fuels and the use of electricity.	Related
B22 Site Decommissioning	Once the facility is no longer operational, the site may need to be decommissioned. This may involve the disassembly of the equipment, demolition of on-site structures, disposal of some materials, environmental restoration, re-grading, planting or seeding, and transportation of materials off-site. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels and electricity used to power equipment required to decommission the site.	Related

2.5 Selection of Relevant Project and Baseline SS's

Each of the SS's from the project and baseline condition were compared and evaluated as to their relevancy using the guidance provided in the Draft Guide to Protocol Developers, Alberta Environment 2009. The justification for the exclusion or conditions upon which SS's may be excluded is provided in **TABLE 2.4** below. All other SS's listed previously are included.

TABLE 2.4: Comparison of SS's

1. Identified SS	2. Baseline (C, R, A)	3. Project (C, R, A)	4. Include or Exclude from Quantification	5. Justification for Inclusion / Exclusion
Upstream SS's				
P1a Cattle Husbandry	N/A	Related	Exclude	Excluded as animal husbandry is functionally equivalent to the baseline scenario.
B1a Cattle Husbandry	Related	N/A	Exclude	
P1b Cattle Production	N/A	Related	Exclude	Excluded as the project cattle production greenhouse gas emissions is functionally equivalent to the baseline scenario.
B1b Cattle Production	Related	N/A	Exclude	
P2 Cattle Transportation	N/A	Related	Exclude	Excluded as the emissions from transportation are likely functionally equivalent to the baseline scenario.
B2 Cattle Transportation	Related	N/A	Exclude	
P3 Feed Production	N/A	Related	Exclude	Excluded as the introduction of Low Residual Feed Intake cattle across many operations is unlikely to affect the distribution of the types of feed production upstream from the project. Baseline and project conditions will be functionally equivalent.
B3 Feed Production	Related	N/A	Exclude	
P4 Feed Transportation	N/A	Related	Exclude	Excluded as the emissions from transportation are likely functionally equivalent to the baseline scenario.
B4 Feed Transportation	Related	N/A	Exclude	
P5 Production of Other Agricultural Inputs	N/A	Related	Exclude	Excluded as upstream production of other agricultural inputs are not impacted by the implementation of the project and as such the baseline and project conditions will be functionally equivalent.
B5 Production of Other Agricultural Inputs	Related	N/A	Exclude	
P6 Transportation of Other Agricultural Inputs	N/A	Related	Exclude	Excluded as the emissions from transportation are likely functionally equivalent to the baseline scenario.
B6 Transportation of Other Agricultural Inputs	Related	N/A	Exclude	
P7 Fuel Extraction and Processing	N/A	Related	Exclude	Excluded as these SS's are not relevant to the project as the emissions from these practises are covered under proposed greenhouse gas regulations.
B7 Fuel Extraction and Processing	Related	N/A	Exclude	
P8 Fuel Delivery	N/A	Related	Exclude	Excluded as these SS's are not relevant to the project as the emissions from these practises are covered under proposed greenhouse gas regulations.
B8 Fuel Delivery	Related	N/A	Exclude	
P16 Electricity Usage	N/A	Related	Exclude	Excluded as these SS's are not relevant to the project as the emissions from these practises are covered under proposed greenhouse gas regulations.
B16 Electricity Usage	Related	N/A	Exclude	
Onsite SS's				
P9 Farm Operation	N/A	Controlled	Exclude	Excluded as beef production is not impacted by the implementation of the

B9 Farm Operation	Controlled	N/A	Exclude	project and as such the baseline and project conditions will be functionally equivalent.
P10 Feed Consumption	N/A	Controlled	**Include**	Included, as this is the one of the main criteria for this project in determining the amount of GHG emission reductions due to selection for the low residual feed intake animals.
B10 Feed Consumption	Controlled	N/A	**Include**	
P13 Manure Storage and Handling	N/A	Controlled	**Include**	Included, as the introduction and selection of the low RFI cattle into an operation, across many operations, (while there will be a reduction in amount of manure produced) is unlikely to affect the way manure is stored and or managed between baseline and project.
B13 Manure Storage and Handling	Controlled	N/A	**Include**	
P14 Manure Transportation	N/A	Controlled	Exclude	Excluded as the emissions from transportation are likely functionally equivalent to the baseline scenario.
B14 Manure Transportation	Controlled	N/A	Exclude	
P15 Land Application	N/A	Controlled	**Include**	Included, as the introduction and selection of the low RFI cattle into an operation, across many operations, is unlikely to affect the way manure is applied, nor will supplemental Nitrogen need to be applied in the project as a result of less manure being generated in the project condition. The main reason for this is that manure is spread only on 5% of the land base in Alberta. The distance that manure is hauled from the confined feeding operation is constrained by economic circumstances. This means that the same lands typically receives manure. It is unlikely that the incremental reductions in manure production between baseline and project condition would require the use of any supplemental N.
B15 Land Application	Controlled	N/A	**Include**	
Downstream SS's				
P11 Finished Cattle Transportation	N/A	Related	Exclude	Excluded as the emissions from transportation are likely functionally equivalent to the baseline scenario.
B11 Finished Cattle Transportation	Related	N/A	Exclude	
P12 Processing and Distribution	N/A	Related	Exclude	Excluded as the emissions from processing and distribution are likely functionally equivalent to the baseline scenario.
B12 Processing and Distribution	Related	N/A	Exclude	
Other				
P17 Development of Site	N/A	Related	Exclude	Emissions from site development are not material given the long project life, and the minimal site development typically required.
B17 Development of Site	Related	N/A	Exclude	Emissions from site development are not material for the baseline condition given the minimal site development typically required.
P18 Building Equipment	N/A	Related	Exclude	Emissions from building equipment are not material given the long project life, and the minimal building equipment typically required.
B18 Building Equipment	Related	N/A	Exclude	Emissions from building equipment are not material for the baseline

				condition given the minimal building equipment typically required.
P19 Transportation of Equipment	N/A	Related	Exclude	Emissions from transportation of equipment are not material given the long project life, and the minimal transportation of equipment typically required.
B19 Transportation of Equipment	Related	N/A	Exclude	Emissions from transportation of equipment are not material for the baseline condition given the minimal transportation of equipment typically required.
P20 Construction on Site	N/A	Related	Exclude	Emissions from construction on site are not material given the long project life, and the minimal construction on site typically required.
B20 Construction on Site	Related	N/A	Exclude	Emissions from construction on site are not material for the baseline condition given the minimal construction on site typically required.
P21 Testing of Equipment	N/A	Related	Exclude	Emissions from testing of equipment are not material given the long project life, and the minimal testing of equipment typically required.
B21 Testing of Equipment	Related	N/A	Exclude	Emissions from testing of equipment are not material for the baseline condition given the minimal testing of equipment typically required.
P22 Site Decommissioning	N/A	Related	Exclude	Emissions from decommissioning are not material given the long project life, and the minimal decommissioning typically required.
B22 Site Decommissioning	Related	N/A	Exclude	Emissions from decommissioning are not material for the baseline condition given the minimal decommissioning typically required.

2.6 Quantification of Reductions and Removals of Relevant SS's

2.6.1 Quantification Approaches

Quantification of GHG reduction in cattle with low residual feed intake (RFI)

The production of methane from enteric fermentation in cattle can be measured directly in metabolic chambers or indirectly using tracers such as sulphur hexafluoride. These are short duration techniques, and are expensive, cumbersome and not practical under normal farming conditions. Hence they are useful research tools but not practical quantification method for methane production. The scientific evidence for the relationship between selection for low RFI and reduction in methane production indicates that this is through the reduction in feed intake and improved diet dry matter digestibility. This reduction in feed intake is captured by RFI indices, since it is the reduction in feed intake relative to the expected feed intake for the size and growth of the animal. Measured as kg of feed (DM basis) per day, this should form the basis of any project for GHG emission reduction from selection for low RFI.

The protocol is based on genetic selection for low RFI, hence the genetic merit (expressed as EBV) of an animal for RFI (rather than the phenotypic measure) should be used for quantification of reductions in GHG emissions.

The preferred method of calculating greenhouse gas production from enteric fermentation and manure production in the baseline and project conditions for groupings of animals on similar rations is through collecting actual DMI intakes from farm data. However, estimates of DMI from IPCC Tier 2 (IPCC 2006), calculated form Cowbytes or similar computer programs, can also be used in standard equations (e.g. IPCC 2006) to estimate the greenhouse gas production from enteric fermentation and manure production (alternate performance standard approach to baselines).

Thus the first step in calculating emission reductions in this protocol is to estimate the expected ***percentage reduction*** in DMI for the project animals, relative to that of the base year animals – for cattle groupings of similar weight and ration. The second step is to estimate actual reductions in DMI for the year of interest (typically the current year for which a GHG assertion will be made, e.g. 2009).

The actual reduction in DMI due to selection for low RFI-EBV cattle is then calculated as:

> (Estimated mean DMI for e.g 2009) x (percentage change in DMI between project and base year animals)/100

Please refer to **Appendix B** for a sample calculation.

Estimating reductions in GHG emissions

These estimates of DMI can then be used in the standard IPCC (2006) equations to estimate the greenhouse gas production from enteric fermentation due to feed consumption and manure production (per the methodologies and equations in Table 2.5). The greenhouse gas production of these animals can then be compared with those obtained from using the estimated DMI for the year of interest (2009 in the above example). Please refer to Appendix B for a robust example of the application of the method.

Quantification of the reductions, removals and reversals of relevant SS's for each of the greenhouse gases will be completed using the methodologies outlined in **TABLE 2.5**, below. A listing of relevant emission factors is provided in **Appendix A**. These calculation methodologies serve to complete the following three equations for calculating the emission reductions from the comparison of the baseline and project conditions.

$$\text{Emission Reduction} = \text{Emissions}_{\text{Baseline}} - \text{Emissions}_{\text{Project}}$$

$$\text{Emissions}_{\text{Baseline}} = \text{Emissions}_{\text{Cattle}}$$

$$\text{Emissions}_{\text{Project}} = \text{Emissions}_{\text{Cattle (* RFI EBV)}}$$

Where:

$\text{Emissions}_{\text{Baseline}}$ = sum of the emissions under the baseline condition.

$\text{Emissions}_{\text{Cattle}}$ = emissions under B10 Feed Consumption; B15 Land Application; B13 Manure Storage and Handling

$\text{Emissions}_{\text{Project}}$ = sum of the emissions under the project condition.

$\text{Emissions}_{\text{Cattle RFI-EBV}}$= emissions under P10 Feed Consumption; P15 Land Application; P13 Manure Storage and Handling

1 **TABLE 2.5: Quantification Procedures**

1.0 Project / Baseline SS	2. Parameter / Variable	3. Unit	4. Measured / Estimated	5. Method	6. Frequency	7. Justify measurement or estimation and frequency
SS's						
P10 Feed Consumption (for Certified RFI-EBV cattle)	$Emissions_{Cattle} = \Sigma (Number_{Production\ i} * DOF_i * DMI_i * GE_{Diet} * (EF_{Enteric\ i} / 100\%) / EC_{Methane})$					
	Enteric Emissions from Cattle for each feed regime within each weight grouping / $Emissions_{Cattle}$	kg CH_4 / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	Number of Cattle in Grouping i / $Number_{Production\ i}$	Head	Measured	Direct measurement of number of head sent to slaughter within each grouping of animals.	Continuous	Direct measurement is the highest level possible.
	Days on Feed for Each Feed Regime for RFI-EBV Cattle in Grouping i / DOF_i	Days	Measured	Direct measurement of days at the feedlot.	Continuous	Direct measurement is the highest level possible.
	Dry Matter Intake for Each Feed Regime for Cattle in Grouping i / DMI_i	$kg_{dry\ matter}$ / head / day	Estimated	Estimated based on average mass of feed provided to cattle during period on diet.	Continuous	Based on actual feed delivery records to each pen.
	Default value Gross energy content (GE) of the diet GE_{Diet}	MJ / $kg_{dry\ matter}$	Estimated	18.45 MJ / $kg_{dry\ matter}$ for diets with no edible oils added to the diet.	Annual	Set based on best available science and in reference to the IPCC, 2006 guidance (Section 10.4.2).
	Emission Factor for Enteric Emissions for Each Feed Regime in Grouping i / $EF_{Enteric\ i}$	%	Calculated	Derived for Low RFI-EBV animals through calculating the reduction in expected GE value or % methane lost as a function of Gross Energy in the diet	Continuous	Calculated using Example Equations in Appendix B; Step 6.
	Energy Content of Methane / $EC_{Methane}$	MJ / $kg_{methane}$	Estimated	55.65 MJ / $kg_{methane}$	Annual	Conversion factor taken from IPCC, 2006 guidance (Section 10.3.2).
B10 Feed Consumption	$Emissions_{Cattle} = \Sigma\Sigma (Number_{Production\ i} * DOF * DMI_I * GE_{Diet} * (EF_{Enteric\ i} / 100\%) / EC_{Methane})$					
	Enteric Emissions from Cattle for each feed regime within	kg CH_4 / day / per weight	N/A	N/A	N/A	Quantity being calculated.

	each weight grouping / $Emissions_{Cattle}$	grouping				
	Number of Cattle in Grouping i / $Number_{Production\ i}$	Head	Measured	Direct measurement of number of head sent to slaughter within each grouping of animals.	Continuous	Direct measurement is the highest level possible.
	Days on Feed for Each Feed Regime for Cattle in Grouping i / DOF_i	Days	Estimated	Average for cattle in weight grouping over the three years prior to the implementation of the project.	Annual	Based on available farm records.
	Dry Matter Intake for Each Feed Regime for Cattle in Grouping i / DMI_i	$kg_{dry\ matter}$ / head / day	Estimated	Estimated based on average mass of feed provided to cattle during period on diet.	Continuous	Based on actual feed delivery records to each pen.
	Default value Gross energy content (GE) of the diet GE_{Diet}	MJ / $kg_{dry\ matter}$	Estimated	18.45 MJ / $kg_{dry\ matter}$ for diets with no edible oils added to the diet.	Annual	Set based on best available science and in reference to the IPCC, 2006 guidance (Section 10.4.2).
	Emission Factor for Enteric Emissions for Each Feed Regime in Grouping i / $EF_{Enteric\ i}$	%	Estimated	3.5% for diets with greater than or equal to 90% concentrates and no added edible oils; 6.5% for diets with less than 90% concentrates and no added edible oils.	Continuous	Based on both best available science for beef feeding in Canada (Beauchemin et al 2005)[2] and in reference to the IPCC 2006 guidance.
	Energy Content of Methane / $EC_{Methane}$	MJ / $kg_{methane}$	Estimated	55.65 MJ / $kg_{methane}$	Annual	Conversion factor taken from IPCC, 2006 guidance (Section 10.3.2).

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P13 Manure Storage and P15 Land Application	$VS_i = [(DMI_i * GE_{Diet} * (1 – (TDN_i / 100\%))) + (UE * DMI_I * GE_{Diet})] * ((1 – (Ash / 100\%)) / GE_{Diet})$					
	Daily Volatile Solid Excreted for Livestock in Grouping i and Each Feed Regime / VS_i	kg / head / day	N/A	N/A	N/A	Quantity being calculated.

[2] Beauchemin K.A. and MCGinn, S. M. 2005. Methane emissions from feedlot cattle fed barley and corn diets. J. Anim. Sci. 83:653-651.

(for Certified RFI-EBV cattle)	Dry Matter Intake for Each Feed Regime for Cattle in Grouping i / DMI_i	kg $_{dry\ matter}$ / head / day	Estimated	Estimated based on average mass of feed provided to cattle during period on diet.	Continuous	Based on actual feed delivery records to each pen.
	Default value Gross energy content (GE) of the diet GE_{Diet}	MJ / kg $_{dry\ matter}$	Estimated	18.45 MJ / kg $_{dry\ matter}$	Annual	Conversion factor taken from IPCC, 2006 guidance (Section 10.4.2).
	Total Digestible Nutrients for Each Feed Regime for Cattle in Grouping i / TDN_i	%	Estimated	Estimated based on composition of feed provided to cattle during period on diet.	Continuous	Estimation based on diet composition and/or from direct analysis of the total mixed ration.
	Urinary Energy / UE	-	Estimated	0.04 for diets with less than 90 % concentrates. 0.02 for diets with greater than 90 % concentrates.	Annual	Set based on best available science and in reference to the IPCC, 2006 guidance (Section 10.4.2).
	Ash Content of Manure Calculated as a Fraction of the Dry Matter Feed Intake for Cattle / Ash	%	Estimated	8% for forage based diets and 2% for grain based diets	Annual	Set based on best available science and in reference to the IPCC, 2006 guidance.
	$Emissions_{Manure\ CH4} = \Sigma (Number_{Production\ i} * DOF_i * VS_i * Bo * \rho_{Methane} * (MCF^3 / 100\%))$					
	Methane Emissions from Manure Handling, Storage and Land Application for each feed regime within each weight grouping / $Emissions_{Manure\ CH4}$	kg CH_4 / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	Number of Cattle in Grouping i / $Number_{Production\ i}$	Head	Measured	Direct measurement of number of head sent to slaughter within each grouping of animals.	Continuous	Direct measurement is the highest level possible.

	Days on Feed for Each Feed Regime for Cattle in Grouping i / DOF_i	days	Measured	Direct measurement of days at the feed lot.	Continuous	Direct measurement is the highest level possible.
	Maximum Methane Producing Capacity for Manure Produced / Bo	m^3_{CH4} / $kg_{VS\ Excreted}$	Estimated	0.19 m^3_{CH4} / $kg_{VS\ Excreted}$	Annual	Conversion factor taken from IPCC, 2006 guidance (Table 10A-5).
	Density of Methane / $\rho_{Methane}$	m^3 / kg	Estimated	0.67 m^3 / kg	Annual	Physical property of methane at standard temperature and pressure.
	Methane Conversion Factor / MCF	%	Estimated	The default MCF for pasture, range, and/or paddock system is 1.0% while that for solid storage is 2.0%. A value of 1.6% could be used for a system that assumes 40% of the manure was produced on pasture while 60% was produced in feedlot and stored in the solid form.	Annual	Set based on best available science and in reference to the IPCC 2006 guidance.
	$Nitrogen_{Excreted\ i} = (DMI_i * ((CP_i / 100\%) / CF_{Protein})) * (1 - Nitrogen_{Retention})$					
	Nitrogen Excreted by the Livestock in Grouping i / $Nitrogen_{Excreted\ i}$	kg / head / day	N/A	N/A	N/A	Quantity being calculated.
	Dry Matter Intake for Each Feed Regime for Cattle in Grouping i / DMI_i	$kg_{dry\ matter}$ / head / day	Estimated	Estimated based on average mass of feed provided to cattle during period on diet.	Continuous	Based on actual feed delivery records to each pen.
	Percent Crude Protein in Diet for Each Feed Regime in Cattle in Grouping i / CP_i	%	Estimated	Estimated based on composition of feed provided to cattle during period on diet.	Continuous	Estimation based on diet composition and/or from direct analysis of the total mixed ration.

	Conversion from Mass of Dietary Protein to Mass of Dietary Nitrogen	$kg_{feed\ protein}$ / $kg_{nitrogen}$	Estimated	6.25 $kg_{feed\ protein}$ / $kg_{nitrogen}$	Annual	Conversion factor taken from IPCC, 2006 guidance (Section 10.5.2).
	Fraction of Annual Nitrogen Intake Retained / Nitrogen $_{Retention}$	$kg_{retained}$ / kg_{intake}	Estimated	0.07 $kg_{retained}$ / kg_{intake}	Annual	Factor taken from IPCC, 2006 guidance (Table 10.20).
	$Emissions_{Direct\ Nitrous\ Oxide} = \Sigma\ (Number_{Production\ i} * DOF_i * Nitrogen_{Excreted\ I} * CF_{Manure}) * 44 / 28$					
	Direct Emissions of Nitrous Oxide from Manure for each feed regime within each weight grouping / $Emissions_{Direct\ Nitrous\ Oxide}$	kg N_2O / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	CF_{Manure}	-	Estimated	0.02 $kg_{N2O\text{-}N}$ / $kg_{Nitrogen\ Excreted}$	Annual	Set based on best available science and in reference to the IPCC.
	$Emissions_{Direct\ Storage} = \Sigma\ (Number_{Production\ i} * DOF_i * Nitrogen_{Excreted\ i} * Frac_{Storage} * EF_{Storage}) * 44 / 28$					
	Direct Emissions of Nitrous Oxide from Manure Storage / $Emissions_{Direct\ Storage}$	kg N_2O / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	$Frac_{Storage}$	-	Estimated	0.8	Annual	Set based on best available science and in reference to the IPCC
	$EF_{Storage}$	$kg_{N2O\text{-}N}$ / $kg_{Nitrogen\ Excreted}$	Estimated	0.007 $kg_{N2O\text{-}N}$ / $kg_{Nitrogen\ Excreted}$	Annual	Set based on best available science and in reference to the IPCC
	$Emissions_{Indirect\ Volatization} = \Sigma\ (Number_{Production\ i} * DOF_i * Nitrogen_{Excreted\ i} * Frac_{Volatization} * EF_{Volatization}) * 44 / 28$					

	Indirect Emissions of Nitrous Oxide from Volatilization for each feed regime within each weight grouping / Emissions $_{Indirect\ Volatization}$	kg N_2O / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	Frac $_{Volatization}$	-	Estimated	0.2	Annual	Set based on best available science and in reference to the IPCC
	EF $_{Volatization}$	kg $_{N2O\text{-}N}$ / kg $_{Nitrogen\ Excreted}$	Estimated	0.01 kg $_{N2O\text{-}N}$ / kg $_{Nitrogen\ Excreted}$	Annual	Set based on best available science and in reference to the IPCC
	Emissions $_{Indirect\ Leaching}$ = Σ (Number $_{Production\ i}$ * DOF $_i$ * Nitrogen $_{Excreted\ i}$ * Frac $_{Leach}$ * EF $_{Leach}$) * 44 / 28					
	Indirect Emissions of Nitrous Oxide from Leaching for each feed regime within each weight grouping / Emissions $_{Indirect\ Leach}$	kg N_2O / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	Frac $_{Leach}$	-	Estimated	0.1	Annual	Set based on best available science and in reference to the IPCC
	EF $_{Leach}$	kg $_{N2O\text{-}N}$ / kg $_{Nitrogen\ Excreted}$	Estimated	0.0125 kg $_{N2O\text{-}N}$ / kg $_{Nitrogen\ Excreted}$	Annual	Set based on best available science and in reference to the IPCC
B13 Manure Storage and B15 Land Application	VS $_i$ = [(DMI $_i$ * GE $_{Diet}$ * (1 – (TDN $_i$ / 100%))) + (UE * DMI $_I$ * GE $_{Diet}$)] * ((1 – (Ash / 100%)) / GE $_{Diet}$)					
	Daily Volatile Solid Excreted for Livestock in Grouping i and Each Feed Regime / VS $_i$	kg / head / day	N/A	N/A	N/A	Quantity being calculated.
	Dry Matter Intake for Each Feed Regime for Cattle in Grouping i / DMI $_i$	kg $_{dry\ matter}$ / head / day	Estimated	Estimated based on average mass of feed provided to cattle during period on diet.	Continuous	Based on actual feed delivery records to each pen.

	Default value Gross energy content (GE) of the diet GE_{Diet}	MJ / $kg_{dry\ matter}$	Estimated	18.45 MJ / $kg_{dry\ matter}$	Annual	Conversion factor taken from IPCC, 2006 guidance (Section 10.4.2).
	Total Digestible Nutrients for Each Feed Regime for Cattle in Grouping i / TDN_i	%	Estimated	Estimated based on composition of feed provided to cattle during period on diet.	Continuous	Estimation based on diet composition and/or from direct analysis of the total mixed ration.
	Urinary Energy / UE	-	Estimated	0.04 for diets with less than 90 % concentrates. 0.02 for diets with greater than 90 % concentrates.	Annual	Set based on best available science and in reference to the IPCC, 2006 guidance (Section 10.4.2).
	Ash Content of Manure Calculated as a Fraction of the Dry Matter Feed Intake for Cattle / Ash	%	Estimated	8% for forage based diets and 2% for grain based diets	Annual	Set based on best available science and in reference to the IPCC, 2006 guidance.
	$Emissions_{Manure\ CH4} = \Sigma\Sigma (Number_{Production\ i} * DOF_i * VS_i * Bo * \rho_{Methane} * (MCF / 100\%))$					
	Methane Emissions from Manure Handling, Storage and Land Application for each feed regime within each weight grouping / $Emissions_{Manure\ CH4}$	kg CH_4 / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	Number of Cattle in Grouping i / $Number_{Production\ i}$	Head	Measured	Direct measurement of number of head sent to slaughter within each grouping of animals.	Continuous	Direct measurement is the highest level possible.
	Days on Feed for Each Feed Regime for Cattle in Grouping i / DOF_i	Days	Estimated	Average for cattle in weight grouping over the three years prior to the implementation of the project.	Annual	Based on available farm records.

	Maximum Methane Producing Capacity for Manure Produced / Bo	m^3_{CH4} / $kg_{VS\ Excreted}$	Estimated	0.19 m^3_{CH4} / $kg_{VS\ Excreted}$	Annual	Conversion factor taken from IPCC, 2006 guidance (Table 10A-5).
	Density of Methane / $\rho_{Methane}$	m^3 / kg	Estimated	0.67 m^3 / kg	Annual	Physical property of methane at standard temperature and pressure.
	Methane Conversion Factor / MCF	%	Estimated	The default MCF for pasture, range, and/or paddock system is 1.0% while that for solid storage is 2.0%. A values of 1.6% could be used for a system that assumes 40% of the manure was produced on pasture while 60% was produced in feedlot and stored in the solid form.	Annual	Set based on best available science and in reference to the IPCC, 2006 guidance.
	$Nitrogen_{Excreted\ i} = DMI_i * (CP_i / 100\%) / CF_{Protein} * (1 - Nitrogen_{Retention})$					
	Nitrogen Excreted by the Livestock in Grouping i / $Nitrogen_{Excreted\ i}$	kg / head / day	N/A	N/A	N/A	Quantity being calculated.
	Dry Matter Intake for Each Feed Regime for Cattle in Grouping i / DMI_i	$kg_{dry\ matter}$ / head / day	Estimated	Estimated based on average mass of feed provided to cattle during period on diet.	Continuous	Estimation based on farm records.
	Percent Crude Protein in Diet for Each Feed Regime in Cattle in Grouping i / CP_i	%	Estimated	Estimated based on composition of feed provided to cattle during period on diet.	Continuous	Estimation based on diet composition and/or from direct analysis of the total mixed ration.
	Conversion from Mass of Dietary Protein to Mass of Dietary Nitrogen	$kg_{feed\ protein}$ / $kg_{nitrogen}$	Estimated	6.25 $kg_{feed\ protein}$ / $kg_{nitrogen}$	Annual	Conversion factor taken from IPCC, 2006 guidance (Section 10.5.2).

	Fraction of Annual Nitrogen Intake Retained / Nitrogen $_{Retention}$	kg $_{retained}$ / kg $_{intake}$	Estimated	0.07 kg $_{retained}$ / kg $_{intake}$	Annual	Factor taken from IPCC, 2006 guidance (Table 10.20).
	Emissions $_{Direct\ Nitrous\ Oxide}$ = ΣΣ (Number $_{Production\ i}$ * DOF $_i$ * Nitrogen $_{Excreted\ i}$ * CF $_{Manure}$) * 44 / 28					
	Direct Emissions of Nitrous Oxide from Manure for each feed regime within each weight grouping / Emissions $_{Direct\ Nitrous\ Oxide}$	Kg N_2O / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	CF $_{Manure}$	-	Estimated	0.02 kg $_{N2O-N}$ / kg $_{Nitrogen\ Excreted}$	Annual	Set based on best available science and in reference to the IPCC.
	Emissions $_{Direct\ Storage}$ = ΣΣ (Number $_{Production\ i}$ * DOF $_i$ * Nitrogen $_{Excreted\ i}$ * Frac $_{Storage}$ * EF $_{Storage}$) * 44 / 28					
	Direct Emissions of Nitrous Oxide from Manure Storage for each feed regime within each weight grouping / Emissions $_{Direct\ Storage}$	kg N_2O / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	Frac $_{Storage}$	-	Estimated	0.8	Annual	Set based on best available science and in reference to the IPCC
	EF $_{Storage}$	kg $_{N2O-N}$ / kg $_{Nitrogen\ Excreted}$	Estimated	0.007 kg $_{N2O-N}$ / kg $_{Nitrogen\ Excreted}$	Annual	Set based on best available science and in reference to the IPCC
	Emissions $_{Indirect\ Volatization}$ = ΣΣ (Number $_{Production\ i}$ * DOF $_i$ * Nitrogen $_{Excreted\ i}$ * Frac $_{Volatizaton}$ * EF $_{Volatization}$) * 44 / 28					

	Indirect Emissions of Nitrous Oxide from Volatization for each feed regime within each weight grouping / Emissions $_{Indirect\ Volatization}$	kg N_2O / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	Frac $_{Volatization}$	-	Estimated	0.2	Annual	Set based on best available science and in reference to the IPCC
	EF $_{Volatization}$	kg $_{N2O-N}$ / kg $_{Nitrogen\ Excreted}$	Estimated	0.01 kg $_{N2O-N}$ / kg $_{Nitrogen\ Excreted}$	Annual	Set based on best available science and in reference to the IPCC
	Emissions $_{Indirect\ Leaching}$ = ΣΣ (Number $_{Production\ i}$ * DOF $_i$ * Nitrogen $_{Excreted\ i}$ * Frac $_{Leach}$ * EF $_{Leach}$) * 44 / 28					
	Indirect Emissions of Nitrous Oxide from Leaching for each feed regime within each weight grouping / Emissions $_{Indirect\ Leach}$	kg N_2O / day / per weight grouping	N/A	N/A	N/A	Quantity being calculated.
	Frac $_{Leach}$	-	Estimated	0.1	Annual	Set based on best available science and in reference to the IPCC
	EF $_{Leach}$	kg $_{N2O-N}$ / kg $_{Nitrogen\ Excreted}$	Estimated	0.0125 kg $_{N2O-N}$ / kg $_{Nitrogen\ Excreted}$	Annual	Set based on best available science and in reference to the IPCC

Notes: 1) 44/28 represents the conversion factor from N_2O-N to N_2O

2) The diet characteristics (DMI, TDN and CP) are to be the same in the baseline and project condition.

2.6.2. Contingent Data Approaches

Contingent means for calculating or estimating the required data for the equations outlined in **Section 2.6.1** are summarized in **TABLE 2.6**, below.

2.7 Management of Data Quality

In general, data quality management must include sufficient data capture such that the mass and energy balances may be easily performed with the need for minimal assumptions and use of contingency procedures. The data should be of sufficient quality to fulfill the quantification requirements and be substantiated by company records for the purpose of verification.

The project developer shall establish and apply quality management procedures to manage all data and information. Written procedures should be established for each measurement task outlining responsibility, timing and record location requirements. The greater the rigour of the management system for the data, the more easily a verification and potential government audits will be to conduct for the project.

2.7.1 Record Keeping

Record keeping practises should include:

a. Electronic recording of values of logged primary parameters for each measurement interval;
b. Printing of monthly back-up hard copies of all logged data;
c. Written logs of operations and maintenance of the project system including notation of all shut-downs, start-ups and process adjustments;
d. Retention of copies of logs and all logged data for a period of 7 years; and
e. Keeping all records available for review by a verification body.

2.7.2 Quality Assurance/Quality Control (QA/QC)

QA/QC can also be applied to add confidence that all measurements and calculations have been made correctly. These include, but are not limited to:

a Protecting monitoring equipment (sealed meters and data loggers);
b Protecting records of monitored data (hard copy and electronic storage);
c Checking data integrity on a regular and periodic basis (manual assessment, comparing redundant metered data, and detection of outstanding data/records);
d Comparing current estimates with previous estimates as a ‘reality check’;
e Provide sufficient training to operators to perform maintenance and calibration of monitoring devices;
f Establish minimum experience and requirements for operators in charge of project and monitoring; and
g Performing recalculations to make sure no mathematical errors have been made.

TABLE 2.6: Contingent Data Collection Procedures

1.0 Project / Baseline SS	2. Parameter / Variable	3. Unit	4. Measured / Estimated	5. Contingency Method	6. Frequency	7. Justify measurement or estimation and frequency
Project SS's						
P1b Cattle Production and P10 Feed Consumption	Mass of Cattle Produced / Mass Production	kg beef	Estimated	Estimation based on number of head of cattle brought to slaughter and average weight for most recent period.	Monthly	Provides a reasonable estimate for the given period.
P13 Manure Storage and P15 Land Application	Mass of Cattle Produced / Mass Production	kg beef	Estimated	Estimation based on number of head of cattle brought to slaughter and average weight for most recent period.	Monthly	Provides a reasonable estimate for the given period.
Baseline SS's						
B1b Cattle Production and B10 Feed Consumption	Mass of Cattle Produced / Mass Production	kg beef	Estimated	Estimation based on number of head of cattle brought to slaughter and average weight for most recent period.	Monthly	Provides a reasonable estimate for the given period.
B13 Manure Storage and B15 Land Application	Mass of Cattle Produced / Mass Production	kg beef	Estimated	Estimation based on number of head of cattle brought to slaughter and average weight for most recent period.	Monthly	Provides a reasonable estimate for the given period.

APPENDIX A:

Relevant Emission Factors

Table A1: Intergovernmental Panel of Climate Change (IPCC) – Global Warming Potentials (2nd Assessment)

Specified Gas	Formula	100-year GWP
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous Oxide	N_2O	310
Sulphur Hexafluoride	SF_6	23900
Perfluorocarbons (PFC)		
Perfluoromethane	CF_4	6500
Perfluoroethane	C_2F_6	9200
Perfluoropropane	C_3F_8	7000
Perfluorobutane	C_4F_{10}	7000
Perfluorocyclobutane	c-C_4F_8	8700
Perfluoropentane	C_5F_{12}	7500
Perfluorohexane	C_6F_{14}	7400
Hydrofluorocarbons (HFC)		
HFC-23	CHF_3	11700
HFC-32	CH_2F_2	650
HFC-41	CH_3F	150
HFC-43-10mee	$C_5H_2F_{10}$ (structure: $CF_3CHFCHFCF_2CF_3$)	1300
HFC-125	C_2HF_5	2800
HFC-134	$C_2H_2F_4$ (structure: CHF_2CHF_2)	1000
HFC-134a	$C_2H_2F_4$ (structure: CH_2FCF_3)	1300
HFC-143	$C_2H_3F_3$ (structure: CHF_2CH_2F)	300
HFC-143a	$C_2H_3F_3$ (structure: CF_3CH_3)	3800
HFC-152a	$C_2H_4F_2$ (structure: CH_3CHF_2)	140
HFC-227ea	C_3HF_7 (structure: CF_3CHFCF_3)	2900
HFC-236fa	$C_3H_2F_6$ (structure: $CF_3CH_2CF_3$)	6300
HFC-245ca	$C_3H_3F_5$ (structure: $CH_2FCF_2CHF_2$)	560

All values interpreted from Volume 1 of the technical report: A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H2S) Emissions by the Upstream Oil and Gas Industry dated September 2004 completed by Clearstone Engineering Ltd. on behalf of the Canadian Association of Petroleum Producers (CAPP).

Table A2: Emission Intensity of Fuel Extraction and Production (Diesel, Natural Gas, and Gasoline)

Diesel		
Production		
Emissions Factor (CO_2)	0.138	kg CO_2 per Litre
Emissions Factor (CH_4)	0.0109	kg CH_4 per Litre
Emissions Factor (N_2O)	0.000004	kg N_2O per Litre
Natural Gas		
Extraction		
Emissions Factor (CO_2)	0.043	kg CO_2 per m^3
Emissions Factor (CH_4)	0.0023	kg CH_4 per m^3
Emissions Factor (N_2O)	0.000004	kg N_2O per m^3
Processing		
Emissions Factor (CO_2)	0.090	kg CO_2 per m^3
Emissions Factor (CH_4)	0.0003	kg CH_4 per m^3

Emissions Factor (N_2O)	0.000003	kg N_2O per m^3
Gasoline		
Production		
Emissions Factor (CO_2)	0.138	kg CO_2 per Litre
Emissions Factor (CH_4)	0.0109	kg CH_4 per Litre
Emissions Factor (N_2O)	0.000004	kg N_2O per Litre

Table A3: Emission Intensity of Combustion (Diesel, Natural Gas and Gasoline)

Diesel		
Emissions Factor (CO_2)	2.730	kg CO_2 per Litre
Emissions Factor (CH_4)	0.000133	kg CH_4 per Litre
Emissions Factor (N_2O)	0.0004	kg N_2O per Litre
Natural Gas		
Electric Utilities		
Emissions Factor (CO_2)	1.891	kg CO_2 per m^3
Emissions Factor (CH_4)	0.00049	kg CH_4 per m^3
Emissions Factor (N_2O)	0.000049	kg N_2O per m^3
Gasoline		
Light Duty Gasoline Trucks		
Emissions Factor (CO_2)	2.360	kg CO_2 per Litre
Emissions Factor (CH_4)	0.00013	kg CH_4 per Litre
Emissions Factor (N_2O)	0.000025	kg N_2O per Litre

APPENDIX B:

Sample Calculation

SAMPLE CALCULATION:

Estimating reduction in feed intake

In this example it was assumed that four low RFI breeding bulls (mean EBV = -0.5 kg DM/day; accuracy=63%) were purchased and mated to 100 cows. An 86% calf crop was assumed, resulting in 43 slaughter steers, 23 slaughter heifers and 20 replacement heifers. Cow fertility, calf crop weaned and cow culling rates were not affected. Cattle were harvested at 18-months of age and low RFI bulls, slaughter cattle and replacement heifers were followed for a period of three years from when the bulls were purchased (Tables 1-4). The following steps are recommended to calculate the reduction of greenhouse gases from enteric fermentation and from manure handling, storage and land application:

STEP 1: Identify categories of cattle affected by the protocol. In this case cattle categories would include slaughter steer and heifer calves, replacement heifers and feed efficient breeding bulls.

STEP 2: Identify the period over which you will be calculating GHG emissions. In this case we will track the cattle over 3 years from the time the low RFI were purchased and delivered to the farm.

STEP 3: Identify the diet and days on each diet for each cattle category (Table 1).

STEP 4: Identify the start weight and the desired rate of gain of each cattle category. This will allow calculation of mid-point weight for the feeding period and calculation of dry matter intake based on IPCC Tier 2 equations, Cowbytes or similar computer programs (e.g., NRC 2001) or from actual historic data (Table 1).

STEP 5: Calculate the GHG emissions for each animal category and each diet for enteric fermentation (Table 1) and manure handling, storage and land application (Table 2) for the BASELINE condition.

STEP 6: Calculate the GHG emissions for each animal category and each diet for enteric fermentation (Table 3) and manure handling, storage and land application (Table 4) for the PROJECT condition. The dry matter intake (DMI) for the PROJECT condition is estimated from the ***expected percentage reduction in DMI*** of the animal of interest relative to that of the base year animals.
Then ***calculate the project methane lost as a percentage of Gross Energy Intake (GEI) relative to baseline – i.e. the Emission Factor*** **- $EF_{Enteric}$.** in Table 2.5; P10 Feed Consumption.

For the sires measured for RFI:

<u>*Available information*</u>

Phenotypic RFI mean for 4 LOW RFI sires	-1.25 kg DM/day
Average Certified RFI_P EBV of 4 sires:	-0.50 kg DM/day
Base Year mean DMI for bulls tested for RFI:	10 kg DM/day (*adjusted to 10 MJ ME/kg DM*)

Percentage change in DMI of LOW RFI sires relative to his test station contemporaries.

Percentage change = (-1.25 kg DM/day x 0.75)/ 10 kg DM/day x 100 = 9.375%. The phenotype correlation between test station performance and performance on-farm or in the feedlot is estimated at 0.75. Therefore we expect this bull to consume 9.375% less feed when returned to the cow-calf ranch or if the estimated BASELINE DMI is 12 kg DM/day, the reduction in DMI for the LOW RFI bulls will be:

Reduction in DMI= 12 kg DM/day x (9.375 / 100) = 1.125 kg DM/day

Hence PROJECT DMI for the specified period = 12 – 1.125 = 10.875 kg DM/day.

The PROJECT methane lost as percentage of GEI is 1-(9.375/100) x methane emission factor (EF) for that diet. For example if the EF is 6.5% then the PROJECT EF= (1-(9.375/100) x 6.5 = 5.89% of GEI is lost as methane.

For the steer or heifer progeny

<u>*Available information*</u>

Average Certified RFI_P EBV of 4 sires:	-0.50 kg DM/day
Certified RFI_P EBV of dam:	Not known
Base Year for bulls tested for RFI Mean DMI:	10 kg DM/day (*adjusted to 10 MJ ME/kg DM*)

<u>*Percentage change in DMI (due to genetic selection) of the bull relative to DMI of base year:*</u>

Assigned RFI_P EBV to steer	= [(Sire RFI_P EBV) + (Dam RFI_P EBV)] / 2
	= [(-0.50) + (0)] / 2
	= -0.25 kg DM/day
Percentage change	= [(RFI_P EBV) / (Base Year mean DMI)] x 100
	= [(-0.25 kg DM/day) / (10 kg DM/day)] x 100
	= -2.5%

Therefore if the estimated BASELINE DMI is 12 kg DM/day, the reduction in DMI due to RFI selection (reduction in DMI) will be:

Reduction in DMI = 12 kg DM/day x (2.5 / 100) = 0.3 kg DM/day.

Hence DMI for the PROJECT condition within animal category and diet = 12 – 0.3 = 11.7 kg DM/day.

The PROJECT methane lost as percentage of GEI is 1-(2.5/100) x methane emission factor (EF) for that diet. For example if the EF is 6.5% then the PROJECT EF= (1-(2.5/100) x 6.5 = 6.34% of GEI is lost as methane.

STEP 7: Calculate the GHG emissions for all categories of animals and diets, sum these values for methane (CH_4) and nitrous oxide (N_2O) separately and then convert to carbon dioxide equivalents (CO_2E) by multiplying CH_4 by 21 and N_2O by 310 (IPCC global warming potentials).

STEP 8: Subtract total CO_2E for BASELINE condition from PROJECT condition for enteric fermentation (Table 1 – Table 3) and for manure handling, storage and land application (Table 2 – Table 4).

STEP 9: Functional Equivalency – Final Step

It is assumed that Baseline and Project conditions are equal in terms of carcass weight as RFI does not affect daily gain or body weight. However, in most actual projects they will not be exactly equal. Therefore the final emissions for the Baseline and Project must be adjusted to a constant carcass weight. This is accomplished using the following procedure:

i) Sum the total GHG emissions for the Baseline condition over the feeding period under consideration (kg CO2e/hd).

ii) Sum the total GHG emissions for the Project condition over the feeding period under consideration (kg CO2e/hd).

iii) Calculate the average carcass weight (or live weight if cattle are not taken to slaughter) of the cattle produced under Baseline conditions (live weight *shrunk weight* dressing percentage). Shrunk weight is assumed to be 96% of live weight and dressing percentage is assumed to be 58% of shrunk weight.

iv) Calculate the average carcass weight (or live weight if cattle are not taken to slaughter) of the cattle produced under Project conditions.

v) Divide the total GHG emissions for the Baseline and Project conditions (kg CO_2e/hd) by their respective average carcass weights (kg CO_2e/kg carcass beef). This value is referred to as the GHG Intensity.

Equalize the Baseline and Project to a GHG emission for a constant carcass weight (345 kg carcass weight) by multiplying the Baseline and project GHG Intensity by 345.

Results:

In this example, the use of four low RFI bulls on a 100 cow herd reduced GHG emissions by 18.724 t CO_2e, with enteric fermentation accounting for a reduction of 13.330 t CO_2e (71.2%) and manure production, storage and handling accounting for a reduction of 5.394 t CO_2e. Continued selection for low RFI males and females will result in the increased accumulation of genetic change and value, even though the first three-year value of GHG reductions is only estimated at $187 CAN ($10 CAN/t CO_2e).

Table B1. Greenhouse gas emissions from ENTERIC FERMENTATION for the BASELINE condition.

Diet, Location & Date	Days on feed	End Age, mo.	ADG kg/d	Start Wt, kg	End Wt, kg	Mid Wt. kg	TDN %	DMI Kg/d	EF % of GEI	Eq. 1 CH_4 lost, g/hd/d	Total CH_4 lost kg/hd
1. Slaughter Steer Calves – birth to slaughter in 18 months; slaughter WT=620.9 kg; carcass WT (620.7x0.96x0.58) = 345.7 kg											
1. Pasture: May-Jul/09	91	3.0	1.07	43.0	140.4	91.7	100.0	1.29	0.00	0.00	0.00
2. Pasture:Aug-Oct/09	92	6.1	1.07	140.4	238.8	189.6	91.0	3.45	6.50	74.35	6.84
3. Pasture:Nov-Jan/10	92	9.2	0.75	238.8	307.8	273.3	63.8	6.80	6.50	146.54	13.48
4. Feedlot:Feb-May 15/10	104	12.6	1.20	307.8	432.6	370.2	70.8	9.11	6.50	196.32	20.42
5. Pasture:May16-Aug 15/10	92	15.7	0.75	432.6	501.6	467.1	63.8	10.16	6.50	218.95	20.14
6. Feedlot:Aug16-Nov 17/10	75	18.2	1.59	501.6	**620.9**	561.2	80.0	12.14	3.50	140.87	10.57
1. Pasture: May-Jul/10;Cyc 2	91	3.0	1.07	43.0	140.4	91.7	100.0	1.29	0.00	0.00	0.00
2. Pasture:Aug-Oct/10;Cyc 2	92	6.1	1.07	140.4	238.8	189.6	91.0	3.45	6.50	74.35	6.84
3. Pasture:Nov-Dec/10;Cyc 2	61	8.2	0.75	238.8	284.6	261.7	63.8	6.80	6.50	146.54	8.94
Sub-Total											87.23
2. Slaughter Heifer Calves – birth to slaughter in 18 months; slaughter WT=620.9 kg; carcass WT (620.7x0.96x0.58) = 345.7 kg											
1. Pasture: May-Jul/09	91	3.0	1.07	43.0	140.4	91.7	100.0	1.29	0.00	0.00	0.00
2. Pasture:Aug-Oct/09	92	6.1	1.07	140.4	238.8	189.6	91.0	3.45	6.50	74.35	6.84
3. Pasture:Nov-Jan/10	92	9.2	0.75	238.8	307.8	273.3	63.8	6.80	6.50	146.54	13.48
4. Feedlot:Feb-May 15/10	104	12.6	1.20	307.8	432.6	370.2	70.8	9.11	6.50	196.32	20.42
5. Pasture:May16-Aug 15/10	92	15.7	0.75	432.6	501.6	467.1	63.8	10.16	6.50	218.95	20.14
6. Feedlot:Aug16-Nov 17/10	75	18.2	1.59	501.6	**620.9**	561.2	80.0	12.14	3.50	140.87	10.57
1. Pasture: May-Jul/10;Cyc 2	91	3.0	1.07	43.0	140.4	91.7	100.0	1.29	0.00	0.00	0.00
2. Pasture:Aug-Oct/10;Cyc 2	92	6.1	1.07	140.4	238.8	189.6	91.0	3.45	6.50	74.35	6.84
3. Pasture:Nov-Dec/10;Cyc 2	61	8.2	0.75	238.8	284.6	261.7	63.8	6.80	6.50	146.54	8.94
Sub-Total											87.23
3. Replacement Heifer Calves											
1. Drylot: Apr-Jun, 09	91	3	1.07	43.0	140.4	91.7	100.0	1.29	0.00	0.00	0.00
2. Pasture: Jul-Sept, 09	92	6	1.07	140.4	238.8	189.6	91.2	3.45	6.50	74.35	6.84
3. Drylot: Oct-Apr, 09/10	212	13	0.70	238.8	387.2	313.0	64.5	7.01	6.50	151.06	32.03
4. Pasture: May-Oct, 10	184	19	0.70	387.2	516.0	451.6	63.8	10.00	6.50	215.50	39.65
5. Drylot: Nov-Dec, 10	61	21	0.50	516.0	546.5	531.2	62.6	10.30	6.50	221.96	13.54
1. Drylot:May-Jul/10;Cycle2	91	3	1.07	43.0	140.4	91.7	100.0	1.29	0.00	0.00	0.00
2. Pasture:Aug-Oct/10;Cyc 2	92	6.1	1.07	140.4	238.8	189.6	91.2	3.45	6.50	74.35	6.84
3 .Drylot:Nov-Dec/10;Cyc 2	61	8.2	0.75	238.8	284.6	261.7	63.8	6.80	6.50	146.54	8.94
Sub-Total											107.84
4. Bulls (27:1 cow to bull ratio)											
1. Drylot; Jan-Apr, 08	120	24	0.50	460	520	490	62.6	11.0	6.50	237.05	28.45
2. Pasture: May-Oct, 08	184	24	0.50	520	612	566	63.8	11.8	6.50	254.29	46.79
1. Drylot: Nov-Dec, 08	61	24	0.50	612	643	627	62.6	13.0	6.50	280.15	17.09
1. Drylot: Jan-Apr, 09	120	24	0.50	643	703	673	62.6	13.6	6.50	293.08	35.17
2. Pasture:May-Oct, 09	184	24	0.50	703	795	749	63.8	14.6	6.50	314.63	57.89
1. Drylot: Nov-Dec, 09	61	24	0.50	795	826	810	62.6	15.7	6.50	338.33	20.64
1. Drylot: Jan-Apr, 10	120	24	0.50	826	886	856	62.6	16.5	6.50	355.57	42.67
2. Pasture: May-Oct, 10	184	24	0.50	886	978	932	63.8	17.2	6.50	370.66	68.20
1. Drylot: Nov-Dec, 10	61	24	0.50	978	1009	993	62.6	18.3	6.50	394.36	24.06
Sub-Total											340.95

Total CO_2E for 4 bulls over 3 years = 4 x 340.95 x 21 = 28639.8 kg
Total CO_2E for 43 slaughter steers over 3 years = 43 x 87.23 x 21 = 78768.7 kg
Total CO_2E for 23 slaughter heifers over 3 years = 23 x 87.23 x 21 = 42132.1 kg
Total CO_2E for 20 replacement heifers over 3 years = 20 x 107.84 x 21= 45292.8 kg

Total CO_2E from enteric fermentation over 3 years for BASELINE conditions 194,833.4 kg or 194.8 t

Diets for slaughter steers and heifers in chronologic order are: 1) 100% milk; 2) 57:43% forage:milk; 3) stockpile pasture; 4) 40% barley, 35% silage, 23% hay, 1% molasses and 1% supplement; 5) pasture; 6) 84.2% barley, 10.5% silage, 3.6% feedlot supplement and 1.6% molasses.

Diets for replacement heifers are: 1) 100% milk; 2) 57:43% forage:milk; 3) 100% barley silage; 4) grass legume pasture and 5) 100% barley silage.

Diets for breeding bulls are: 1) grass hay/TM salt; 2) grass-legume pasture.

Table B2. Greenhouse gas emissions from manure handling, storage and land application for the BASELINE condition.

Period Location	Days on feed	Crude Protein %	TDN %	DMI kg/d	Eq. 2 Daily Volatile solids, kg/hd/day	Eq. 3 Manure handling CH_4 kg/hd	Eq. 4 Daily Nitrogen Excreted kg/hd/day	Eq. 5 Manure N_2O Direct kg/hd	Eq. 6 Manure N_2O Storage kg/hd	Eq. 7 Manure N_2O Volatil-ization kg/hd	Eq. 8 Manure N_2O Leaching kg/hd
1. Slaughter Steer Calves – birth to slaughter in 18 months; slaughter WT=620.9 kg; carcass WT (620.7x0.96x0.58) = 345.7 kg											
1. Pasture	91	26.7	100.0	1.29	0.047	0.005	0.051	0.147	0.041	0.015	0.009
2. Pasture	92	19.0	91.0	3.45	0.413	0.048	0.098	0.282	0.079	0.028	0.015
3. Pasture	92	17.1	63.8	6.80	2.515	0.295	0.173	0.500	0.140	0.050	0.028
4. Feedlot	104	11.8	70.8	9.11	2.783	0.737	0.160	0.523	0.146	0.052	0.050
5. Pasture	92	17.1	63.8	10.16	3.758	0.440	0.259	0.747	0.209	0.075	0.047
6. Feedlot	75	13.1	80.0	12.14	2.617	0.500	0.237	0.558	0.156	0.056	0.035
1. Pasture	91	26.7	100.0	1.29	0.047	0.005	0.051	0.147	0.041	0.015	0.009
2. Pasture	92	19.0	91.0	3.45	0.413	0.048	0.098	0.282	0.079	0.028	0.015
3. Pasture	61	17.1	63.8	6.80	2.515	0.195	0.173	0.332	0.093	0.033	0.021
Sub-Total						2.274		3.517	0.985	0.352	0.220
2. Slaughter Heifer Calves – birth to slaughter in 18 months; slaughter WT=620.9 kg; carcass WT (620.7x0.96x0.58) = 345.7 kg											
1. Pasture	91	26.7	100.0	1.29	0.047	0.005	0.051	0.147	0.041	0.015	0.009
2. Pasture	92	19.0	91.0	3.45	0.413	0.048	0.098	0.282	0.079	0.028	0.015
3. Pasture	92	17.1	63.8	6.80	2.515	0.295	0.173	0.500	0.140	0.050	0.028
4. Feedlot	104	11.8	70.8	9.11	2.783	0.737	0.160	0.523	0.146	0.052	0.050
5. Pasture	92	17.1	63.8	10.16	3.758	0.440	0.259	0.747	0.209	0.075	0.047
6. Feedlot	75	13.1	80.0	12.14	2.617	0.500	0.237	0.558	0.156	0.056	0.035
1. Pasture	91	26.7	100.0	1.29	0.047	0.005	0.051	0.147	0.041	0.015	0.009
2. Pasture	92	19.0	91.0	3.45	0.413	0.048	0.098	0.282	0.079	0.028	0.015
3. Pasture	61	17.1	63.8	6.80	2.515	0.195	0.173	0.332	0.093	0.033	0.021
Sub-Total						2.274		3.517	0.985	0.352	0.220
3. Replacement Heifer Calves											
1. Drylot	91	26.7	100.0	1.29	0.025	0.006	0.051	0.147	0.041	0.015	0.009
2. Pasture	92	19.0	91.0	3.45	0.372	0.087	0.098	0.282	0.079	0.028	0.018
3. Drylot	212	11.1	62.6	7.01	2.707	1.461	0.116	0.771	0.216	0.077	0.048
4. Pasture	184	17.1	63.8	10.00	3.744	1.754	0.254	1.471	0.412	0.147	0.092
5. Drylot	61	11.1	62.6	10.30	3.977	0.618	0.169	0.323	0.090	0.032	0.020
1. Drylot	91	26.7	100.0	1.29	0.025	0.006	0.051	0.147	0.041	0.015	0.009
2. Pasture	92	19.0	91.0	3.45	0.372	0.087	0.098	0.282	0.079	0.028	0.018
3 .Drylot	61	11.1	62.6	7.01	2.707	0.420	0.116	0.222	0.062	0.022	0.014
Sub-Total						4.439		3.645	1.021	0.365	0.228
4. Bulls (27:1 cow to bull ratio)											
1. Drylot	120	10.7	62.3	11.00	4.280	1.308	0.175	0.611	0.185	0.066	0.041
2. Pasture	184	17.1	63.8	11.80	4.417	2.069	0.300	1.736	0.486	0.174	0.109
1. Drylot	61	10.7	62.3	13.00	5.058	0.786	0.207	0.397	0.111	0.040	0.025
1. Drylot	120	10.7	62.3	13.60	5.291	1.617	0.217	0.817	0.229	0.082	0.051
2. Pasture	184	17.1	63.8	14.6	5.466	2.560	0.371	2.148	0.602	0.215	0.134
1. Drylot	61	10.7	62.3	15.7	6.108	0.949	0.250	0.479	0.134	0.048	0.030
1. Drylot	120	10.7	62.3	16.5	6.419	1.961	0.263	0.991	0.277	0.099	0.062
2. Pasture	184	17.1	63.8	17.2	6.439	3.016	0.438	2.531	0.709	0.253	0.158
1. Drylot	61	10.7	62.3	18.3	7.120	1.106	0.291	0.559	0.156	0.056	0.035
Sub-Total						15.372		10.318	2.889	1.032	0.645
Total CO_2E for 4 bulls over 3 years	= (4 x 15.372 x 21) + (4 x ((10.318 + 2.889 + 1.032 + 0.645) x 310)) = 19747.4 kg										
Total CO_2E for 43 slaughter steers over 3 years	= (43 x 2.274 x 21) + (43 x ((3.517 + 0.985 + 0.352 + 0.220) x 310)) = 69686.6 kg										
Total CO_2E for 23 slaughter heifers over 3 years	= (23 x 2.274 x 21) + (23 x ((3.517 + 0.985 + 0.352 + 0.220) x 310)) = 37274.2 kg										
Total CO_2E for 20 replacement heifers over 3 years	= (20 x 4.439 x 21) + (20 x ((3.645 + 1.021 + 0.365 + 0.228) x 310)) = 34465.7 kg										
Total CO_2E from manure handling, storage & land application over 3 years for BASELINE conditions 161,173.6 kg or 161.2 t											

Table B3. Greenhouse gas emissions from ENTERIC FERMENTATION for the PROJECT condition.

Diet, Location & Date	Days on feed	End Age, mo.	ADG kg/d	Start Wt, kg	End Wt, kg	Mid Wt. kg	TDN %	DMI Kg/d	EF % of GEI	Eq. 1 CH_4 lost, g/hd/d	Total CH_4 lost kg/hd
1. Slaughter Steer Calves – birth to slaughter in 18 months; slaughter WT=620.9 kg; carcass WT (620.7x0.96x0.58) = 345.7 kg											
1. Pasture: May-Jul/09	91	3.0	1.07	43.0	140.4	91.7	100.0	1.26	0.00	0.00	0.00
2. Pasture:Aug-Oct/09	92	6.1	1.07	140.4	238.8	189.6	91.0	3.36	6.34	70.68	6.50
3. Pasture:Nov-Jan/10	92	9.2	0.75	238.8	307.8	273.3	63.8	6.63	6.34	139.30	12.82
4. Feedlot:Feb-May 15/10	104	12.6	1.20	307.8	432.6	370.2	70.8	8.88	6.34	186.63	19.41
5. Pasture:May16-Aug 15/10	92	15.7	0.75	432.6	501.6	467.1	63.8	9.91	6.34	208.14	19.15
6. Feedlot:Aug16-Nov 17/10	75	18.2	1.59	501.6	**620.9**	561.2	80.0	11.84	3.41	133.91	10.04
1. Pasture: May-Jul/10;Cyc 2	91	3.0	1.07	43.0	140.4	91.7	100.0	1.26	0.00	0.00	0.00
2. Pasture:Aug-Oct/10;Cyc 2	92	6.1	1.07	140.4	238.8	189.6	91.0	3.36	6.34	70.68	6.50
3. Pasture:Nov-Dec/10;Cyc 2	61	8.2	0.75	238.8	284.6	261.7	63.8	6.63	6.34	139.30	8.50
Sub-Total											82.92
2. Slaughter Heifer Calves – birth to slaughter in 18 months; slaughter WT=620.9 kg; carcass WT (620.7x0.96x0.58) = 345.7 kg											
1. Pasture: May-Jul/09	91	3.0	1.07	43.0	140.4	91.7	100.0	1.26	0.00	0.00	0.00
2. Pasture:Aug-Oct/09	92	6.1	1.07	140.4	238.8	189.6	91.0	3.36	6.34	70.68	6.50
3. Pasture:Nov-Jan/10	92	9.2	0.75	238.8	307.8	273.3	63.8	6.63	6.34	139.30	12.82
4. Feedlot:Feb-May 15/10	104	12.6	1.20	307.8	432.6	370.2	70.8	8.88	6.34	186.63	19.41
5. Pasture:May16-Aug 15/10	92	15.7	0.75	432.6	501.6	467.1	63.8	9.91	6.34	208.14	19.15
6. Feedlot:Aug16-Nov 17/10	75	18.2	1.59	501.6	**620.9**	561.2	80.0	11.84	3.41	133.91	10.04
1. Pasture: May-Jul/10;Cyc 2	91	3.0	1.07	43.0	140.4	91.7	100.0	1.26	0.00	0.00	0.00
2. Pasture:Aug-Oct/10;Cyc 2	92	6.1	1.07	140.4	238.8	189.6	91.0	3.36	6.34	70.68	6.50
3. Pasture:Nov-Dec/10;Cyc 2	61	8.2	0.75	238.8	284.6	261.7	63.8	6.63	6.34	139.30	8.50
Sub-Total											82.92
3. Replacement Heifer Calves											
1. Drylot: Apr-Jun, 09	91	3	1.07	43.0	140.4	91.7	100.0	1.26	0.00	0.00	0.00
2. Pasture: Jul-Sept, 09	92	6	1.07	140.4	238.8	189.6	91.2	3.36	6.34	70.68	6.50
3. Drylot: Oct-Apr, 09/10	212	13	0.70	238.8	387.2	313.0	64.5	6.83	6.34	143.61	30.44
4. Pasture: May-Oct, 10	184	19	0.70	387.2	516.0	451.6	63.8	9.75	6.34	204.86	37.69
5. Drylot: Nov-Dec, 10	61	21	0.50	516.0	546.5	531.2	62.6	10.04	6.34	211.00	12.87
1. Drylot:May-Jul/10;Cycle2	91	3	1.07	43.0	140.4	91.7	100.0	1.26	0.00	0.00	0.00
2. Pasture:Aug-Oct/10;Cyc 2	92	6.1	1.07	140.4	238.8	189.6	91.2	3.36	6.34	70.68	6.50
3 .Drylot:Nov-Dec/10;Cyc 2	61	8.2	0.75	238.8	284.6	261.7	63.8	6.63	6.34	139.30	8.50
Sub-Total											102.51
4. Bulls (27:1 cow to bull ratio)											
1. Drylot; Jan-Apr, 08	120	24	0.50	460	520	490	62.6	9.97	5.89	194.69	23.36
2. Pasture: May-Oct, 08	184	24	0.50	520	612	566	63.8	10.69	5.89	208.84	38.43
1. Drylot: Nov-Dec, 08	61	24	0.50	612	643	627	62.6	11.78	5.89	230.08	14.04
1. Drylot: Jan-Apr, 09	120	24	0.50	643	703	673	62.6	12.33	5.89	240.70	28.88
2. Pasture:May-Oct, 09	184	24	0.50	703	795	749	63.8	13.23	5.89	258.40	47.55
1. Drylot: Nov-Dec, 09	61	24	0.50	795	826	810	62.6	14.23	5.89	277.87	16.95
1. Drylot: Jan-Apr, 10	120	24	0.50	826	886	856	62.6	14.95	5.89	292.03	35.04
2. Pasture: May-Oct, 10	184	24	0.50	886	978	932	63.8	15.59	5.89	304.42	56.01
1. Drylot: Nov-Dec, 10	61	24	0.50	978	1009	993	62.6	16.58	5.89	323.89	19.76
Sub-Total											280.02
Total CO_2E for 4 bulls over 3 years = 4 x 280.02 x 21 = 23521.7 kg											
Total CO_2E for 43 slaughter steers over 3 years = 43 x 82.92 x 21 = 74876.8 kg											
Total CO_2E for 23 slaughter heifers over 3 years = 23 x 82.92 x 21 = 40050.4 kg											
Total CO_2E for 20 replacement heifers over 3 years = 20 x 102.51 x 21= 43054.2 kg											
Total CO_2E from enteric fermentation over 3 years for PROJECT conditions 181,503 kg or 181.5 t											

Diets for slaughter steers and heifers in chronologic order are: 1) 100% milk; 2) 57:43% forage:milk; 3) stockpile pasture; 4) 40% barley, 35% silage, 23% hay, 1% molasses and 1% supplement; 5) pasture; 6) 84.2% barley, 10.5% silage, 3.6% feedlot supplement and 1.6% molasses.

Diets for replacement heifers are: 1) 100% milk; 2) 57:43% forage:milk; 3) 100% barley silage; 4) grass legume pasture and 5) 100% barley silage.

Diets for breeding bulls are: 1) grass hay/TM salt; 2) grass-legume pasture.

Table B4. Greenhouse gas emissions from manure handling, storage and land application for the PROJECT condition.

Period Location	Days on feed	Crude Protein %	TDN %	DMI kg/d	Eq. 2 Daily Volatile solids, kg/hd/day	Eq. 3 Manure handling CH_4 kg/hd	Eq. 4 Daily Nitrogen Excreted kg/hd/day	Eq. 5 Manure N_2O Direct kg/hd	Eq. 6 Manure N_2O Storage kg/hd	Eq. 7 Manure N_2O Volatil-ization kg/hd	Eq. 8 Manure N_2O Leaching kg/hd
1. Slaughter Steer Calves – birth to slaughter in 18 months; slaughter WT=620.9 kg; carcass WT (620.7x0.96x0.58) = 345.7 kg											
1. Pasture	91	26.7	100.0	1.26	0.046	0.005	0.050	0.143	0.040	0.014	0.009
2. Pasture	92	19.0	91.0	3.36	0.402	0.047	0.095	0.275	0.077	0.027	0.017
3. Pasture	92	17.1	63.8	6.63	2.452	0.287	0.169	0.488	0.137	0.049	0.030
4. Feedlot	104	11.8	70.8	8.88	2.712	0.718	0.156	0.510	0.143	0.051	0.032
5. Pasture	92	17.1	63.8	9.91	3.665	0.429	0.252	0.727	0.204	0.073	0.046
6. Feedlot	75	13.1	80.0	11.84	2.553	0.487	0.231	0.544	0.152	0.054	0.034
1. Pasture	91	26.7	100.0	1.26	0.046	0.005	0.050	0.143	0.040	0.014	0.009
2. Pasture	92	19.0	91.0	3.36	0.402	0.047	0.095	0.275	0.077	0.027	0.017
3. Pasture	61	17.1	63.8	6.63	2.452	0.190	0.169	0.323	0.091	0.032	0.020
Sub-Total						2.217		3.430	0.960	0.343	0.214
2. Slaughter Heifer Calves – birth to slaughter in 18 months; slaughter WT=620.9 kg; carcass WT (620.7x0.96x0.58) = 345.7 kg											
1. Pasture	91	26.7	100.0	1.26	0.046	0.005	0.050	0.143	0.040	0.014	0.009
2. Pasture	92	19.0	91.0	3.36	0.402	0.047	0.095	0.275	0.077	0.027	0.017
3. Pasture	92	17.1	63.8	6.63	2.452	0.287	0.169	0.488	0.137	0.049	0.030
4. Feedlot	104	11.8	70.8	8.88	2.712	0.718	0.156	0.510	0.143	0.051	0.032
5. Pasture	92	17.1	63.8	9.91	3.665	0.429	0.252	0.727	0.204	0.073	0.046
6. Feedlot	75	13.1	80.0	11.84	2.553	0.487	0.231	0.544	0.152	0.054	0.034
1. Pasture	91	26.7	100.0	1.26	0.046	0.005	0.050	0.143	0.040	0.014	0.009
2. Pasture	92	19.0	91.0	3.36	0.402	0.047	0.095	0.275	0.077	0.027	0.017
3. Pasture	61	17.1	63.8	6.63	2.452	0.190	0.169	0.323	0.091	0.032	0.020
Sub-Total						2.217		3.430	0.960	0.343	0.214
3. Replacement Heifer Calves											
1. Drylot	91	26.7	100.0	1.26	0.025	0.006	0.050	0.143	0.040	0.014	0.009
2. Pasture	92	19.0	91.0	3.36	0.362	0.085	0.095	0.275	0.077	0.027	0.017
3. Drylot	212	11.1	62.6	6.83	2.637	1.423	0.113	0.752	0.210	0.075	0.047
4. Pasture	184	17.1	63.8	9.75	3.650	1.710	0.248	1.435	0.402	0.143	0.090
5. Drylot	61	11.1	62.6	10.04	3.877	0.602	0.164	0.315	0.088	0.032	0.020
1. Drylot	91	26.7	100.0	1.26	0.025	0.006	0.050	0.143	0.040	0.014	0.009
2. Pasture	92	19.0	91.0	3.36	0.362	0.085	0.095	0.275	0.077	0.027	0.017
3 .Drylot	61	11.1	62.6	6.63	2.637	0.410	0.113	0.216	0.061	0.022	0.014
Sub-Total						4.326		3.553	0.995	0.355	0.222
4. Bulls (27:1 cow to bull ratio)											
1. Drylot	120	10.7	62.3	9.97	3.850	1.176	0.159	0.599	0.168	0.060	0.037
2. Pasture	184	17.1	63.8	10.69	4.002	1.875	0.272	1.573	0.440	0.157	0.098
1. Drylot	61	10.7	62.3	11.78	4.548	0.706	0.188	0.360	0.101	0.036	0.022
1. Drylot	120	10.7	62.3	12.33	4.761	1.455	0.196	0.740	0.207	0.074	0.046
2. Pasture	184	17.1	63.8	13.23	4.953	2.320	0.337	1.947	0.545	0.195	0.122
1. Drylot	61	10.7	62.3	14.23	5.494	0.853	0.227	0.434	0.122	0.043	0.027
1. Drylot	120	10.7	62.3	14.95	5.772	1.764	0.238	0.898	0.251	0.090	0.056
2. Pasture	184	17.1	63.8	15.59	5.836	2.734	0.397	2.294	0.642	0.229	0.143
1. Drylot	61	10.7	62.3	16.58	6.402	0.994	0.264	0.506	0.142	0.051	0.032
Sub-Total						13.877		9.350	2.618	0.935	0.584
Total CO_2E for 4 bulls over 3 years					= (4 x 13.877 x 21) + (4 x ((9.350 + 2.618 + 0.935 + 0.584) x 310))						= 17890.8 kg
Total CO_2E for 43 slaughter steers over 3 years					= (43 x 2.217 x 21) + (43 x ((3.430 + 0.960 + 0.343 + 0.214) x 310))						= 67948.6 kg
Total CO_2E for 23 slaughter heifers over 3 years					= (23 x 2.217 x 21) + (23 x ((3.430 + 0.960 + 0.343 + 0.214) x 310))						= 36344.6 kg
Total CO_2E for 20 replacement heifers over 3 years					= (20 x 4.326 x 21) + (20 x ((3.553 + 0.995 + 0.355 + 0.222) x 310))						= 33595.8 kg
Total CO_2E from manure handling, storage & land application over 3 years for PROJECT conditions 155,779.8 kg or 155.8 t											

APPENDIX C:

Testing Criteria for RFI

Applicable Alberta Testing Facilities for Certified RFI-EBVs

The following facilities are fitted with the GrowSafe System (GrowSafe Systems Ltd., Airdrie, Alberta) for monitoring individual animal feed intake and are aware of the Standard Operating Procedures (Beef Improvement Federation 2009) for measuring individual animal feed intake and for calculating RFI. New facilities could be added to this list as the RFI and GrowSafe technologies are adopted by the beef cattle industry.

Established Alberta RFI Testing Facilities as of October, 2009:

- Morison Feedlot, Airdrie, Alberta;
- Cattleland Feedyards, Strathmore, Alberta;
- Namaka Farms, Strathmore, Alberta;
- Olds College, Olds, Alberta;
- Lacombe Research Centre, Lacombe, Alberta;
- Lethbridge Research Centre, Lethbridge, Alberta;
- Kinsella Ranch, Kinsella, Alberta.

Below is an exert from the Beef Improvement Federation's "General Minimum Guidelines for Recording Individual Feed Intake in Growing Bulls and Steer and Heifer Progeny, Chapter 7 – Feed Intake and Efficiency by D. H. Crews, Jr., G. E. Carstens, J. A. Basarab, R. A. Hill, and M. K. Nielsen available at: http://www.beefimprovement.org/library/06guidelines.pdf. The Beef Improvement Federation website is available at: http://www.beefimprovement.org.

CHAPTER 7 – FEED INTAKE and EFFICIENCY

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Since the mid 1990's there has been a dramatic increase in the capacity for collection of individual feed intake data on group fed beef cattle, due largely to technological advances in equipment used for collecting intake records. Concurrently, research on the genetic, nutritional, physiological, and economic aspects of feed intake and efficiency has increased. Genetic evaluation programs for feed intake and efficiency are developing, recognizing the economic relevance of cost-stream input traits to genetic improvement in profitability. Amidst these advancements, the phenotypic definition of feed efficiency remains somewhat contentious, although the economic importance of intake as the largest non-fixed cost of beef production is well known. The objective of these guidelines is to recommend procedures for collection of individual feed intake records on young, growing cattle, and on alternative methods for the expression of feed efficiency.

Equipment and Facilities for Intake Measurement

Several types of equipment are currently available to measure individual feed intake. Reliable data can be obtained with the use of Calan gate systems (http://americancalan.com) as well as with newer designs that utilize electronic scales within feed bunks along with radio frequency animal identification (e.g., GrowSafe

Systems, Ltd.; http://www.growsafe.com). An important distinction is that research has shown the inadequacy of feed intake data for the purposes of genetic evaluation which is derived from animals fed alone in individual confinement pens. Further, in this chapter, it is assumed that individual feed intake data are indeed measured on individual animals housed in groups, rather than from pen-feeding designs where animal is not the experimental unit for intake. Therefore, feed intake phenotypes which are computed as net feed delivered to an entire pen divided by the number of animals in the pen are not equivalent to individual feed intake records in this chapter.

The increase in capacity for collection of feed intake data has come in two forms. With the advent of electronic hardware and software systems, research facilities have been established across North America to increase their ability to conduct experiments where feed intake is of interest. At the same time, existing performance testing centers have retro-fit their facilities with feed intake measurement capabilities. Because most of the equipment mentioned above is scalable, the recommendations in this chapter have been written to accommodate both types of facilities.

Pre-Test Information

For feed intake records to be suitable for inclusion in genetic evaluation programs, pre-test information on individual animals should be recorded. Individual animal identification (e.g., registration number) should be easily compatible with other databases and unique. For example, breed and parentage (pedigree) information allows for merging feed intake records with larger pedigree and performance databases. Classification data required to assemble appropriate contemporary groups should also be recorded according to the requirements and advice of the genetic evaluation service provider. If tested animals will receive genetic evaluations independent of their larger breed population, additional data will be required. Most NCE systems utilize a minimum of a three generation ancestral pedigree (beginning with animals with data) to compute EPD. Depending on the traits included in genetic evaluation(s), birth and weaning dates and weights and age of dam information to define contemporary groups will also be required. It is recommended that test centers consult with genetic evaluation service providers for these data requirements.

Age on Test

It has been shown that feed intake is related to the age of animals when feeding tests are conducted. Animals entering a feed intake test should have actual birth date recorded so that age at the beginning of the test can be calculated. Weaning data are generally required to be collected before animals reach 260 d of age; the age at which an animal begins a feed intake test should be after weaning but not be less than 240 d. Within a feeding contemporary group, animals should have start of test ages within a 60-d range. Feed intake measurement on test should be completed before an animal reaches 390 d of age.

Pre-Conditioning Period

In order to acclimate to the testing facility, a pre-conditioning or warm-up period of at least 21 d should be incorporated into the test calendar. During this period, animals should adapt to the test facility and the final test diet. Daily individual feed intake records collected during the pre-conditioning period or when animals are consuming transitional diets cannot readily be used in the computation of daily feed intake. Transitional diets are those that differ from the test diet (bulls) or are different from the finishing diet (steers and cull heifers).

Test Period

Research has demonstrated that a minimum of a 70-d test period (following pre-conditioning) is required to accurately compute average daily gain for individual animals. Live weights are recommended to be recorded at equally spaced intervals. In research programs, live weights are often recorded at 2- and 3-week intervals. In central bull test facilities, initial and final weights are regularly estimated as the average of two live weights taken on consecutive days at the beginning and end of the test, respectively. In order to reduce measurement error, serial weighing is likely to result in the most accurate estimates of average daily gain, as long as a minimum of 5-6 weights are recorded at nearly equally spaced intervals over the test period. For a 70-d test, therefore, biweekly weight measurement is recommend, whereas for a 112-d test, recording live weight at 28-d intervals is recommended. Weigh dates must also be recorded to enable the computation of average daily gain (ADG) on test. On test ADG when serial weights are available is computed as the linear slope from the regression of live weight on test day. Linear regressions for individual animals should have R^2 values equal to or greater than 0.95.

Most studies agree that adequate estimates of daily feed intake can be obtained when individual feed intake is recorded for a minimum of 45 d. Tests will likely need to be longer than this minimum in order to accommodate feeding, equipment and computing malfunctions which vary depending on the intake data recording equipment.

The test period should be defined as the final 70 d of a 91-d or longer test. During the test period, animals must be consuming feed at *ad libitum* levels to avoid data bias due to restriction feeding. Wherever possible, daily intake records should be deleted when animals do not have *ad libitum* access to feed. Examples where feeding may be restricted include days when animals are removed from the pen due to maintenance, equipment failure, and sickness, or for collection of related data (e.g., live weights, ultrasound, etc.). Feed intake data recorded on days when animals do not have *ad libitum* access to feed due to feed delivery failures or being absent from the pen should not be used to compute average daily feed intake.

In order to compute start of test, end of test (and days on test), and related metrics, dates of the beginning and end of tests as well as when the pre-conditioning period ended should be recorded. Intake data from days where animals were absent from the pen, or intake data judged to be unusable should be set to missing, or at least corresponding dates indicated so the data can be removed prior to further analyses.

Missing feed intake data may be estimated using a regression approach as suggested by Hebart et al. (2004), however, large (> 5 d) blocks of data cannot be missing at the beginning or end of the test for any animal. If there are some missing data, and usable data includes at least 45 d of intake recording, the missing data need not be replaced or estimated.

Figure 1 depicts a typical feed intake data recording test which conforms to the minimum numbers of days required to collect suitable data.

Figure 1. Feed intake test time line by week (Wk), day (Day), and test day (Test d).

Wk	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Day	0	7	14	21	28	35	42	49	56	63	70	77	84	91
Test d				0	7	14	21	28	35	42	49	56	63	70
LWT[a]	R[e]			Y		Y		Y		Y		Y		Y
RTU[b]				R				R[g]		R[g]				R
PRE[c]	Y[f]	Y	Y											
DMI[d]				Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

[a] Live weight (LWT) is often recorded in research settings every 2 wks, but could be less frequent with longer tests (minimum of 5 – 6 LWT for suitable ADG computation). LWT should be recorded on equally spaced intervals. Computation of average daily gain (ADG) as the average of LWT recorded on 2 consecutive d at the beginning and end of test is more susceptible to measurement error than from serial weights.
[b] Real time ultrasound (RTU) could be collected at the beginning and end of test, serially, or if only once, at the end of test.
[c] PRE = pre-test warm-up period of 21 d for facility and diet acclimation.
[d] Dry matter intake (DMI) data collection period of at least 70 d ensures a minimum of ~ 50 d of usable data. Archer et al. (1997) and Wang et al. (2006) showed an absolute minimum of 35 – 45 d required to obtain accurate estimates of daily dry matter intake. A minimum of 70 d is required (Archer et al., 1997) to compute accurate estimates of average daily gain.
[e] Recommended time of measurement.
[f] Required measurement.
[g] To coincide with LWT recording, RTU measurements can be taken near the midpoint of the test in test facilities where more than two scans are desired.

Test Diets

Diets utilized in feeding tests will vary quite diversely according to animal type, animal gender, environmental constraints, feed ingredient availability, cost, and management. Therefore, data collection should be implemented such that diets can be adjusted insofar as possible to a common nutritional base. All animals within one test should be fed the same test diet, and the diet should be formulated to provide essential nutrients and sufficient energy to ensure expression of animal differences for both production and intake. The ingredient composition of the diet should be recorded, and the ingredient composition of the diet maintained throughout the test period. Samples of diet ingredients or of the complete diet should be obtained during the test, and subsample(s) sent to a commercial laboratory for complete chemical analysis.

There is a growing number of reports in the scientific literature in which growing test diets are adjusted to a common energy content of 2.4 Mcal ME/(kg DM). Diets used in tests with finishing steers should contain at least 2.9 Mcal ME/(kg DM). That is, statistical adjustment to a constant energy density requires recording of enough chemical composition data on the diet(s) to derive metabolizable energy (ME) in megacalories (Mcal) on a dry matter basis. Average daily intake and functions of intake data should be reported on a dry matter basis. Expression of daily feed intake values on a dry matter basis removes variability in the moisture content across a diversity of diets, and increases the comparability across multiple tests and studies. As-fed measurement of daily feed intake can be recorded as well, but for further data analyses, sufficient information must be supplied to convert feed intake to a dry matter basis (DMI).

Pen Stocking Rates

In tests that utilize electronic feed intake recording equipment, managers should strictly adhere to the manufacturer recommendations on animal density (number of animals per feed bunk) to obtain accurate measurements of feed intake. Optimal animal density may need to be adjusted for the age of cattle, energy density of the test diet, and minimum bunk and pen space required per animal. Researchers are encouraged to consult with their local animal care and use committee for these specifications, whereas commercial testing centers should consult with animal scientists or other knowledgeable professionals to ensure that animal numbers per pen is not excessive. It is important to maintain appropriate pen density to facilitate normal feeding behavior, and accurate measurement of *ad libitum* intake.

Measurement of Body Composition

Research suggests that deposition of fat and muscle are related to feed intake (e.g., Basarab et al., 2003; Schenkel et al., 2004). A growing number of studies and testing centers in North America routinely collect body composition data on animals during feed intake testing using real time ultrasound (RTU). For these data to be valid for national cattle evaluation, ultrasound scanning must be conducted according to guidelines established by the appropriate breed association. For the purposes of calculating residual feed intake which is adjusted for body composition, RTU measurements should be taken at least once during the feed intake test, after the pre-conditioning period. If only one RTU scan will be recorded, it is recommended that this measurement be conducted at the end of the test to ensure phenotypic variability in subcutaneous fat depth. Start of test RTU measurements can be used along with end of test measurements to compute change in fat and muscle over the test period. In more intensive studies, serial RTU measurements can be used to compute deposition curves for both fat and muscle.

Data Auditing

For electronic intake data recording systems, data auditing functions monitor the quality of intake records, and are used to judge the suitability of intake data prior to further analyses. Feed delivered to animals and that recorded by the system as consumed should not differ by more than 5%. Technicians should utilize all data integrity features available on individual feed intake recording systems. Once daily dry matter intake is computed for individual animals, simple correlations among intake (DMI), growth rate (ADG), and live weight (LWT) should be computed. Correlations that are not at least moderate and positive indicate suspect data. Researchers and test managers are encouraged to consult with experts to conduct further data auditing to ensure the highest possible integrity of test data before proceeding with further analyses. Additionally, for tests where residual feed intake (RFI) or other measures of efficiency will be computed, the correlations of such measures with their components should be computed and compared to published values. Means and standard deviations of DMI, ADG, and body weight by contemporary group are also useful as low group variation in weight and(or) ADG may explain low correlations among DMI, ADG, and body weight.

Alternative Measures of Feed Efficiency

The primary objective of these guidelines is to make minimum recommendations for the collection of daily feed (dry matter) intake on individual animals. The use of feed intake to compute various alternative measures of feed efficiency depends heavily on the integrity of the intake data. The definition of alternative feed efficiency measurements and their respective utility is the subject of extensive debate among scientists as well as producers. For example, since the 1960's, more than two dozen alternative feed efficiency calculations have been proposed in the scientific literature.

Probably the most common measure in both the scientific literature and industry is feed conversion ratio. In these guidelines, feed conversion ratio (FCR), and(or) it's inverse (gross efficiency), are not considered synonymous with feed efficiency. To remove ambiguity, alternative measurements of feed efficiency will be referenced by their definition (Table 1) rather than with the uninformative term "feed efficiency".

Table 1. Alternative measures of feed efficiency and their definitions.

Measurement	Definition[a]
Feed conversion ratio (FCR)	FCR = DMI / ADG
Residual feed intake 1 (RFI1)	RFI1 = DMI – ($\beta_0 + \beta_1 \times$ ADG + $\beta_2 \times$ MWT) = DMI – E(DMI)
Residual feed intake 2 (RFI2)	RFI2 = DMI – ($\beta_0 + \beta_1 \times$ ADG + $\beta_2 \times$ MWT + $\beta_3 \times$ FAT)
Residual feed intake 3 (RFI3)	RFI3 = DMI – ($\beta_0 + \beta_1 \times$ ADG + $\beta_2 \times$ MWT + $\beta_3 \times$ FAT + $\beta_4 \times$ REA)
Partial efficiency of growth (PEG)	ADG / (DMI – E(DMIm))

[a] On-test abbreviations: DMI = daily dry matter intake, ADG = average daily gain, FAT = ultrasound (RTU) subcutaneous fat depth (or RTU FAT deposition rate per d), REA = RTU longissimus muscle area (or RTU REA deposition rate per d), MWT = metabolic mid-test body size = mid-test $LWT^{0.75}$, E(DMIm) = expected daily DMI for maintenance, and E(DMI) = expected daily DMI based on requirements for growth rate and body size.

The list of alternative measures of feed efficiency listed in Table 1 is not intended to be exhaustive. Rather, the intent is to define, for reference, the more common measures utilized in both science and industry. The traditional measure defined as FCR is very common to existing bull tests and in the feedlot sector of the industry, however, FCR is undesirable with regard to national cattle evaluation. Similar to the other traits defined as ratios (PEG, KR, RGR), FCR and ratio traits in general are unsuitable for genetic evaluation (e.g., see Gunsett, 1984). In addition, FCR has been shown to have antagonistic genetic correlations with mature size and maintenance requirements. In the case of residual feed intake, several definitions are listed which supports the notion of considering "residualization" as a methodology rather than RFI as a static trait. The difference between actual and expected DMI is the universal albeit vague definition of RFI (Koch et al., 1963), however the implementation of RFI is dependent on the type of data available to compute expected DMI.

A considerable volume of research has been published which includes RFI although no constant definition (e.g., RFI1, RFI2, or RFI3 in Table 1) is used across all studies. An important distinction to note, however, is that current RFI methodology relies on the regression approach to compute expected DMI. In older research, expected DMI was computed using published "tabular" values based on large meta-analyses such as NRC. For the purposes of these guidelines, residual feed intake exclusively refers to the residual term from the regression of DMI on its indicators measured on individual animals.

Summary

Routine collection of feed intake data has become a reality for inclusion in genetic improvement programs, and this collection of data is largely built on electronic technologies. Ample evidence exists for the presence of genetic variation available for selection to increase efficiency of beef production; increases in efficiency can result by reducing feed intake while not altering output or performance, or by increasing output while not increasing feed intake, or by some combination of these. Selection toward improved efficiency will be accomplished by a multiple-trait selection index approach that integrates feed intake with measures of output performance.

This chapter provides guidelines for feed intake testing conditions and recording of data that will be used in genetic evaluation systems. These guidelines are for measurement of young, growing animals, not mature cows. Establishment of contemporary groups, pre-test period, and the test period are outlined. The test period when body weight, gain, and feed intake are recorded has a minimum length of 70 d with valid feed intake for at least 45 d. Test diets of approximately 2.4 Mcal ME/(kg DM) are recommended for bulls, whereas test diets for steers should contain at least 2.9 Mcal ME/(kg DM). True energy values for test diets are expected to be recorded, and feed intake adjusted to a dry matter basis.

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