Integrated Manure Utilization System Life-Cycle Value Assessment

IMUS LCVA

FINAL REPORT

October 2005

Jesse Row
Derek Neabel

Contacts

Inquiries regarding this report can be made to:

Jesse Row, Pembina Institute
Ph: (403) 269-3344 ext. 110
Email: jesser@pembina.org

Inquiries regarding the IMUS technology can be made to:

Mike Kotelko, Highmark Renewables Inc.
Ph: (780) 768-2466
Email: mkotelko@highlandbeef.com

Or

Xiaomei Li, Alberta Research Council
Ph: (780) 450-5290
Email : xiaomei@arc.ab.ca

Acknowledgements

The authors would like to acknowledge the input of Xiaomei Li and Earl Jensen of the Alberta Research Council, and Mike Kotelko of Highmark Renewables Inc. into the Life-Cycle Value Assessment process.

The authors would also like to acknowledge Dr. Peter Flynn, Department of Mechanical Engineering, University of Alberta; and Dr. Yongsheng Feng, Department of Renewable Resources, University of Alberta for reviewing and providing feedback on the report.

Disclaimer

The following report considers only the manure management component of intensive livestock operations (feedlots). No attempt has been made to address the overall impacts of these operations within this assessment. Therefore, the analysis and conclusions drawn within are limited to the impacts of manure management and do not include the impacts of other activities within feedlots.

Executive Summary

Since 2001, the Alberta Research Council and Highmark Renewables have been leading the development of an integrated manure utilization system (IMUS) for the livestock industry. The IMUS technology uses manure as a resource to produce electricity, heat, bio-based fertilizer and reusable water. This Life-Cycle Value Assessment (LCVA) focused on evaluating those triple-bottom-line factors of primary importance to government, investors and the livestock industry.

The development of future IMUS plants have the potential to be financially viable if the following targets can be met for a 30,000 head operation: 1) a power purchase price of $90 / MWh on average; 2) a capital cost under $11 million; and 3) an established biofertilizer price of $50 / tonne. These parameters were determined to have the largest impact on the net present value of an IMUS project, and are considered to have a relatively high uncertainty at this stage of development of the IMUS technology.

An IMUS plant is estimated to reduce life-cycle greenhouse gas emissions by 70% to 80% when compared with the current practice of land spreading. This is accomplished through 1) displacing electricity from the provincial grid, 2) reduced emissions during manure storage (due to reduced residence time), and 3) reduced N_2O emissions from manure spreading. Greater accuracy in the results could be obtained through further testing of the direct emission reductions obtained through differences in manure residence times and nitrogen emissions during spreading.

The IMUS also reduces environmental impact in a number of other areas. It reduces the extraction and consumption of non-renewable resources by displacing an estimated 11,700 GJ of coal and natural gas per 1000 head of cattle per year. It virtually eliminates potentially harmful pathogens within manure. And it has the potential to eliminate the environmental hazards associated with the disposal of deadstock. In areas where there is over-application of manure to the land, IMUS can also decrease the potential for nutrient contamination in the land, and ground and surface water.

From a community impact perspective, the IMUS reduces manure odour (a major concern of local residents), lessens truck traffic on public roads, and is expected to contribute to rural economic diversification.

Reporting in detail on the operability of IMUS and its contribution to rural economic diversification was not investigated at this time due to time and data constraints. The market for the IMUS bio-fertilizer is also somewhat uncertain at this time, as it is a new product. Assessment in these areas should be considered in future work.

The benefits from IMUS could be further enhanced in cases where manure is currently over-applied to lands surrounding the feedlot. In these cases, the IMUS bio-fertilizer can be used to displace the use of synthetic fertilizers in other fields. This has the combined effect of reducing the potential for nutrient contamination in land and water surrounding the feedlot, reducing GHG emissions by an additional 290 tpy, and reducing road traffic by about 270 trips or 3,400 km per year for every 1000 head of cattle. It should be noted that this is dependent on the ability to sell bio-fertilizer to local farmers.

The benefits of IMUS could also be further enhanced by utilizing 100% biogas within the plant, as opposed to a mixture of biogas and natural gas.

Over the course of the LCVA, barriers to further implementation of IMUS, as well as emerging opportunities for IMUS developers were identified. These are discussed in more detail within the report conclusions.

Overall, the initial assessments of the IMUS are very positive. Further investigation and demonstration is needed in some key areas to confirm the actual life-cycle performance of the operations, but early indications point towards improved triple-bottom-line performance of manure management for intensive livestock operations.

Table of Contents

1.0 Goal Definition

1.1. Background to the LCVA

Since 2001, the Alberta Research Council and Highmark Renewables have been leading the development of an Integrated Manure Utilization System (IMUS) for the livestock industry. The IMUS technology uses manure as a resource to produce electricity, heat, bio-based fertilizer and reusable water. IMUS is being positioned as a contributor to the long-term sustainable development of the livestock industry and as a low impact renewable energy industry.

Manure management is a critically important component of any intensive livestock operation, and can be the limiting factor to how large the livestock operation is able to grow. The typical method of disposing manure from livestock operations is to spread it on the surrounding farmland. This management practice benefits the land by adding needed nutrients and organic matter, but it also creates potentially hazardous environmental and social side-effects.

The side-effects of greatest concern with intensive livestock operations are the contamination of soil, and surface and ground water with pathogens and excess nutrients; the odour that is created; and the high number of trucks on rural roads. These side-effects of the intensive livestock operation can have serious impacts on the surrounding community particularly as larger amounts of manure are spread over the same amount of land as the operations grow. Manure management, therefore, often becomes the primary barrier to further expansion of the livestock operation.

IMUS uses anaerobic digestion as its primary management step, but the unique features of IMUS is how it uses all of the by-products of anaerobic digestion to create valuable products. The biogas from the anaerobic digester is used to generate electricity and heat. The water and the solids output from the anaerobic digester are separated and treated to produce a biological fertilizer and water, both of which can be used in other farming operations.

An IMUS demonstration plant is now under construction at the Highland Feeders beef cattle feedlot near Vegreville, Alberta and is expected to be operational in May of 2005. Highland Feeders is the fourth largest feedlot in the province (and the country) at 36,000 head of cattle. This plant is expected to demonstrate the feasibility of the IMUS technology for other feedlot operations. Manure management practices and the associated challenges are currently very similar throughout the industry.

This Life-Cycle Value Assessment (LCVA) was initiated by the Alberta Research Council and Highmark Renewables during the construction of the pilot IMUS facility. The purpose of completing the assessment at this time was to assemble some early information about IMUS technology while it is introduced to the public and broader support is sought.

The level of detail desired at this time is relatively general and the analysis focused on compiling currently available information. It is recommended that more detailed investigation of the triple-bottom-line impacts of the IMUS be completed in the future. Additional areas of research include investigation of the impact that the IMUS could have on the livestock industry, regional economies, quality of life for surrounding residents, and the productivity of the surrounding ecosystem. It is also recommended that further investigation be made into some of the input data used in this study in order to improve the accuracy of the results. Several input assumptions that are considered to have high uncertainty are summarized in the Conclusions section.

The report follows a typical LCVA methodology. Section 1 defines the goal of the LCVA including its objectives, the systems to be compared, stakeholders to consider and timelines for decision-making. Section 2 provides the scope of the LCVA, and includes key assumptions, a map of each system and the criteria for system evaluation. Section 3 presents the results of the life-cycle data inventory assessment for each of the evaluation criteria. Finally, overall conclusions are drawn from the results of the analysis including an identification of gaps that exist within the current information, future barriers to implementation of the IMUS, and opportunities that proponents of the IMUS should consider.

1.2 LCVA Objective

The objective of this LCVA is to address the following key question:

> What are the key economic, environmental, and social benefits and risks of the IMUS technology compared to the current method of manure management in a feedlot?

The outcomes of this LCVA are to be considered by the stakeholders identified in Section 1.4.

1.3 System Options

LCVA is a comparison between various options for delivering a particular service or product. Therefore, it is necessary to define which options will be compared within the LCVA. This is done by first identifying all possible options, and then determining which are of greatest importance to investigate, at present, given the resources available.

Table 1.1 contains a full list of possible options for manure management that was compiled during the LCVA kick-off workshop attended by representatives of Highmark Renewables, the Alberta Research Council and the Pembina Institute on October 26, 2004. As the table indicates, the primary interest of the project participants is to compare IMUS to the current practice of manure management, land spreading. Comparison to other alternatives may be taken at a later date.

Table 1.1 System Options

System Option	Included in this LCVA?	Why or Why Not?
IMUS (Anaerobic Digestion and Nutrient Recovery)	Yes	Technology of Interest to Highmark Renewables and the Alberta Research Council
Land Spreading[A]	Yes	Current Practice
Composting	No	Not of Primary Interest to Project Participants at This Time
Pyrolysis		
Incineration		
Bio-oil production		
Bio-gasification		

[A] Further defined in Section 2.1.

1.4 Timelines for Making the Decision

Key deadlines for this decision are:

- On the policy front, there is a bio-energy strategy being released for Alberta on March 31, 2005. Input from industry is required by the end of January.
- May 6, 2005 is the ribbon-cutting event for the IMUS demonstration plant.
- Engagement of investors for future projects is expected to take place within 1 year of the demonstration plant being successfully operational.
- Engagement of the livestock industry is expected to take place following the first year of successful operation of the IMUS demonstration plant.

1.5 Stakeholder Mapping

Stakeholder mapping is used to identify the interests of various parties as they relate to the options being considered. This perspective is used throughout the LCVA in order to guide the generation of useful and relevant information directed towards these stakeholders.

The stakeholder mapping was completed during the LCVA kick-off workshop. Table 1.2 lists the primary stakeholders identified and their interests while Table 1.3 lists the secondary stakeholders.

Table 1.2 Primary Stakeholders and Expected Interests

Stakeholders	Key Questions and Concerns
Government and Policy Makers	• What is the triple bottom line (economic, environmental and social impacts) o Economic viability of the technology o Economic viability of the cattle industry o Environmental sustainability o Addressing of public concerns (groundwater, odour, traffic) • Regulatory policy – there is pressure to introduce new regulations for manure management, food safety, and environmental impact • Should government provide a subsidy for this technology due to the fact that it produces power and mitigates many other risks? • How does this assist rural development?
Potential Investors	• What is the economic viability of the technology? • Will it provide tradable GHG offsets, and how much? • What is the potential for investment or partnerships?
Livestock Industry	• What is the economic viability of the technology? • How does this contribute to the sustainability of my operation? • What are the technical and operational challenges? (beyond normal practices)

Table 1.3 Secondary Stakeholders and Expected Interests

Stakeholders	Key Questions and Concerns
General Public & Neighbours	• What are the environmental and social benefits of this process? o How does it deal with odour issues, pathogens, water contamination, and nutrient contamination?
Energy Producers	• Can the operation use net metering, and if so, how does it pay for transmission and distribution costs?
Green Power Purchasers	• What are the environmental and social benefits of this process? • Is the power Ecologo certified? • How much do the Environmental Certificates cost and what amount of GHG credit does it include? • How does the operation manage the other environmental, health and ethical issues of intensive livestock operations?
Government Funding Agencies (SDTC, TEAM, GMIF)	• What are the environmental and social benefits of this process? • What are the verified GHG reductions as a result of the operations? • Can this technology be applied to municipal organic waste?
Technology and Equipment Vendors	• Is there a future market for IMUS (as a new application of their product)?
Research Community	• Is anaerobic digestion a viable manure management alternative? • A demonstration of advancing technologies from the laboratory to commercialization. • How can gas production and nutrient capture from manure be improved?

2.0 Scoping

The LCVA scoping process is used to both define and focus the assessment prior to the detailed data collection and analysis tasks. This activity provides guidance on the input and output issues of the options being assessed by further defining the systems to be analyzed. It also identifies key triple-bottom-line issues for each option and determines the criteria by which they will be evaluated.

2.1 Key Assumptions and Considerations

Key assumptions associated with the two systems being assessed in this LCVA are:

1. The Integrated Manure Utilization System (IMUS)

   IMUS is defined as the system developed by the Alberta Research Council and Highmark Renewables to convert manure to electricity, heat, biofertilizer and water.

2. Current Practice

   The current practice system is defined as the conventional methods by which the livestock industry typically disposes of their manure through spreading on surrounding farmlands.

   Manure enters three streams of management practices at Highland Feeders, each stream utilizing approximately a third of the total manure.

   - *Direct spreading* – manure is collected in the pens and directly spread to the land in spring and fall.
   - *Simplified composting in the pens* – manure is composted in the pens for approximately six months and then directly spread to the land. Composting manure reduces its volume, weight and odour for land spreading.
   - *Stockpiling in the field* – manure is collected in the pens and transported to the field, where it is stockpiled until it can be spread at appropriate times of the year. Stockpiled manure includes the frozen pen scrapings created during the winter season.

Life-cycle activity maps showing the components of each system can be found in Section 2.2.

In order to equitably compare two or more different systems, each system must deliver the same primary product or service. This is defined as the Functional Unit. The Functional Unit, or basis of comparison, in this LCVA has been defined as:

> 1 Year of Manure Disposal for 1000 Head of Beef Cattle, or 1200 tonnes of dry weight manure

Further equity in the comparison between two or more systems can be achieved by defining identical system by-products. The 'by-products' of the IMUS, relative to the functional unit, are 743 MWh of electricity, 195 kW of heat, 31 tonnes of marketable nitrogen in the form of biofertilizer, the disposal of 93 cows and 1,110,000 litres of water recovered. In order to provide similar products in the Current Practice system, electricity, deadstock disposal, and synthetic fertilizer have been added, as shown in the life-cycle map (Figure 2.2). At this time, the heat and water are not expected to be used in the demonstration project and, therefore, equivalent products have not been added in the Current Practice system.

> It should be noted that the fertilizer applied to the land in each system is not the same, and does not provide the same level of service. In the Current Practice, manure is applied to surrounding farmlands. In the IMUS case, biofertilizer is applied. While these both provide nutrients and organic matter to the soil, they are of different quantities and qualities. In order to better equate the value of fertilizer product, each system was set up to deliver an equivalent amount of nitrogen to the soil. This was accomplished by adding 4.8 tonnes of synthetic fertilizer (urea) to the Current Practice system in order to balance the two systems. It was not possible, however, to easily equate the amount of other nutrients and organic matter applied to the soil or the quality of nutrients and organic matter applied, and therefore should be noted as an inequity within the systems.

A summary of the major system assumptions is listed in Table 2.1. See Appendix A and B for more detailed system assumptions.

Table 2.1 Key System Assumptions

	Current Practice	IMUS
Electricity source	- Mix of all electricity sources in Alberta for 2003 based on total production	- Avg. production is 850 kW including natural gas supplement of 100 kW[A]
Electricity transmission losses	- 4.45% transmission losses - 3.55% distribution losses	- No transmission losses (electricity is used locally) - 3.55% distribution losses
Average distance for trucking solids	- 6 km from pen to field	- 1 km from pen to IMUS - 6 km from IMUS to field
Fertilizer production	- Manure is produced at Highland Feeders - Urea is produced in Redwater, AB	- Bio-fertilizer is produced in IMUS
Fertilizer application	- Fields surrounding the feedlot	- Fields surrounding the feedlot
Deadstock disposal	- Composted on-site	- Used within IMUS
Carbon sequestration	- 11% of the carbon will remain in the soil as soil organic matter [Li 2004]	- 18% of the carbon will remain in the soil as soil organic matter after 50 years [Li 2004]

[A] Natural gas supplement is used during peak times to maximize the economic return of the plant. The engine in the IMUS demonstration project has been sized to accommodate this extra electricity production. Future plants could be sized to run only on biogas.

Sensitivity Analyses

Five separate sensitivity analyses were performed within this LCVA. These are described by the following 'what if' questions:

Emissions Sensitivities

Emission Sensitivity #1: Increased Biofertlizer Distribution

What if the IMUS biofertilizer displaces the use of synthetic fertilizer at farms within the region as opposed to replacing the manure spread on lands surrounding the feedlot?

> The Biofertilizer Distribution Sensitivity assumes that the current practice of spreading manure on surrounding fields provides little value when applied to the field and thus does not need to be replaced when it is diverted to the IMUS plant. This is true of situations where manure is over-applied to the lands directly surrounding the feedlots, thus eliminating any

usefulness for the added nutrients and organic matter that comes from the manure. The biofertilizer is assumed to be transported during the return trip of a truck already delivering feed to the feedlot.

Only 4.8 tonnes of urea is displaced by the IMUS biofertilizer in the base case (the rest displaces manure application), whereas, 76 tonnes of urea are displaced in the Biofertilizer Distribution Sensitivity (i.e. all of the biofertilizer is used to displace the application of urea at farms in the region).

Emission Sensitivity #2: Less Carbon Sequestration

What if the carbon in the biofertilizer is not sequestered as effectively as expected?

There is currently high uncertainty in estimating the amount of carbon sequestration in both systems investigated. The carbon from IMUS biofertilizer is known to be more stable than carbon from manure [Li 2004], but the amount of carbon that will become sequestered in the soil over the long term is uncertain. Therefore, the Carbon Sequestration Sensitivity investigated the impact of a lesser degree of carbon sequestration from the IMUS biofertilizer.

In the base case, 18% of the biofertilizer carbon is assumed to remain as soil organic matter after 50 years; whereas in the Carbon Sequestration Sensitivity, only 14% of the biofertilizer carbon is assumed to remain in the soil as soil organic matter after 50 years.

Emission Sensitivity #3: Increased Rate of N_2O Emission

What if N_2O emissions from manure occur faster than expected (thus increasing the N_2O emissions from manure prior to loading in the IMUS)?

There is relatively high uncertainty regarding the rate of N_2O emissions during manure storage due to a lack of available data. Therefore, a sensitivity on the N_2O emission rate during manure storage was performed.

In the base scenario, it is assumed that, on average, the total emissions, as estimated within Canada’s GHG Inventory, occur during the normal 6 months of residence time that manure spends in the feedlot pens. It was also assumed that if the residence time was reduced to 2 months, the related N_2O emissions would be reduced by 66%.

In the N_2O Emission Rate Sensitivity, a more conservative assumption (from the perspective of the IMUS project) is used. In this scenario, it is

> assumed that the shorter residence time in the IMUS case results in a 33% reduction in emissions. Therefore, the reduction in N_2O emissions from manure storage is half of the amount estimated in the base scenario.

Emission Sensitivity #4: 100% Biogas

What if the IMUS plant uses 100% biogas for electricity generation as opposed to a mixture of biogas and natural gas?

> The IMUS demonstration project has been designed to have approximately 17% of the fuel supply for cogeneration come from natural gas. It is possible, however, for the fuel supply to be 100% biogas. This sensitivity explores the changes to net GHG emissions that would occur if no natural gas was used to supplement fuel supply within the IMUS.

Economic Sensitivity

What if there is a 25% variance in key economic parameters?

> In assessing the economic viability of IMUS, it is important to consider the impact of potential changes to key economic factors, such as the price of equipment or the market value of the products produced. Within this sensitivity, each input parameter was varied by 25% to determine its impact on the overall project’s net present value.

2.2 Life-Cycle Activity Maps

Figure 2.1 and Figure 2.2 outline the unit processes for the IMUS and the Current Practice systems. A full description of each unit process including assumptions can be found in Appendix A and Appendix B.

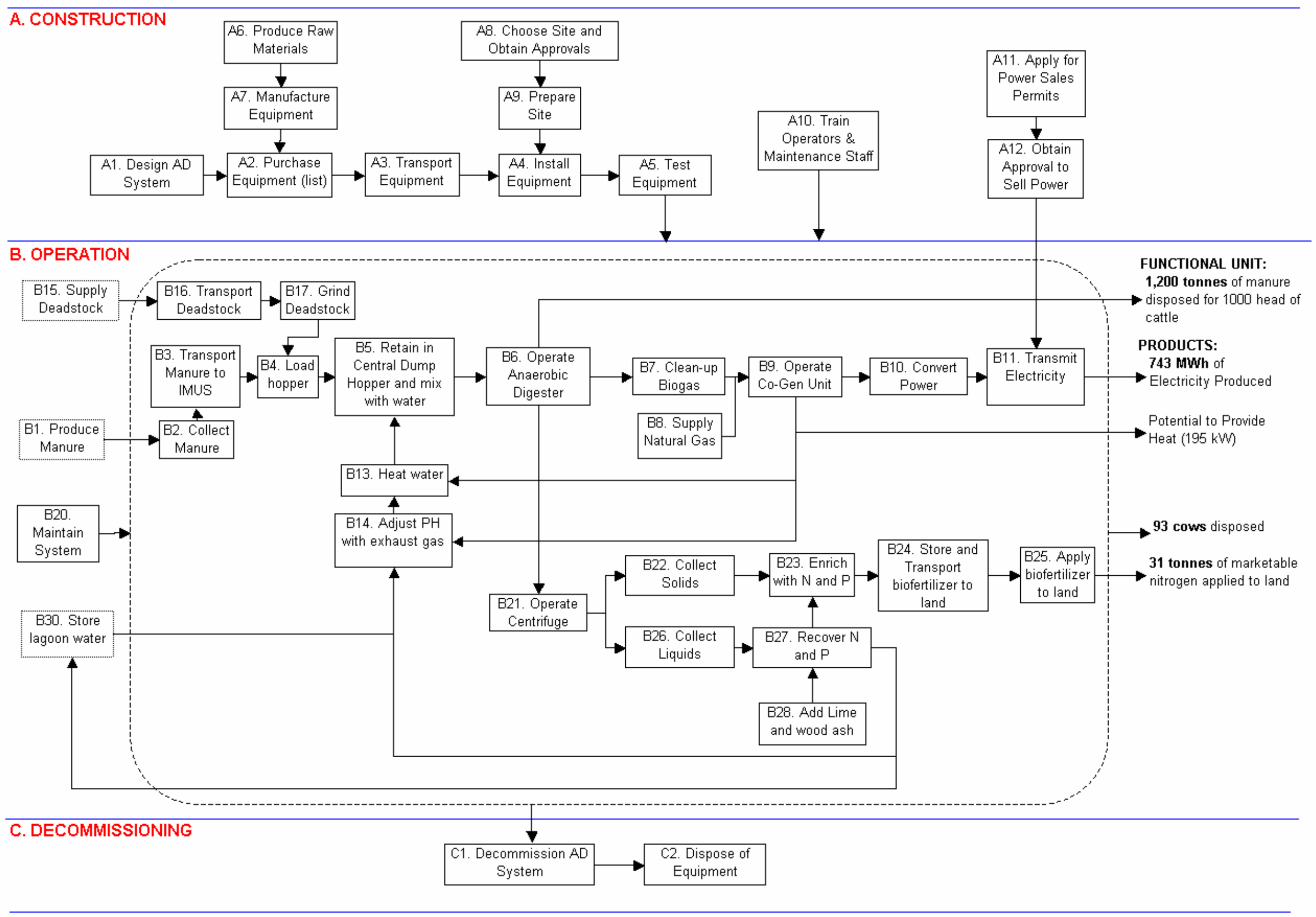

Figure 2.1: Life-Cycle Activity Map of Anaerobic Digester System

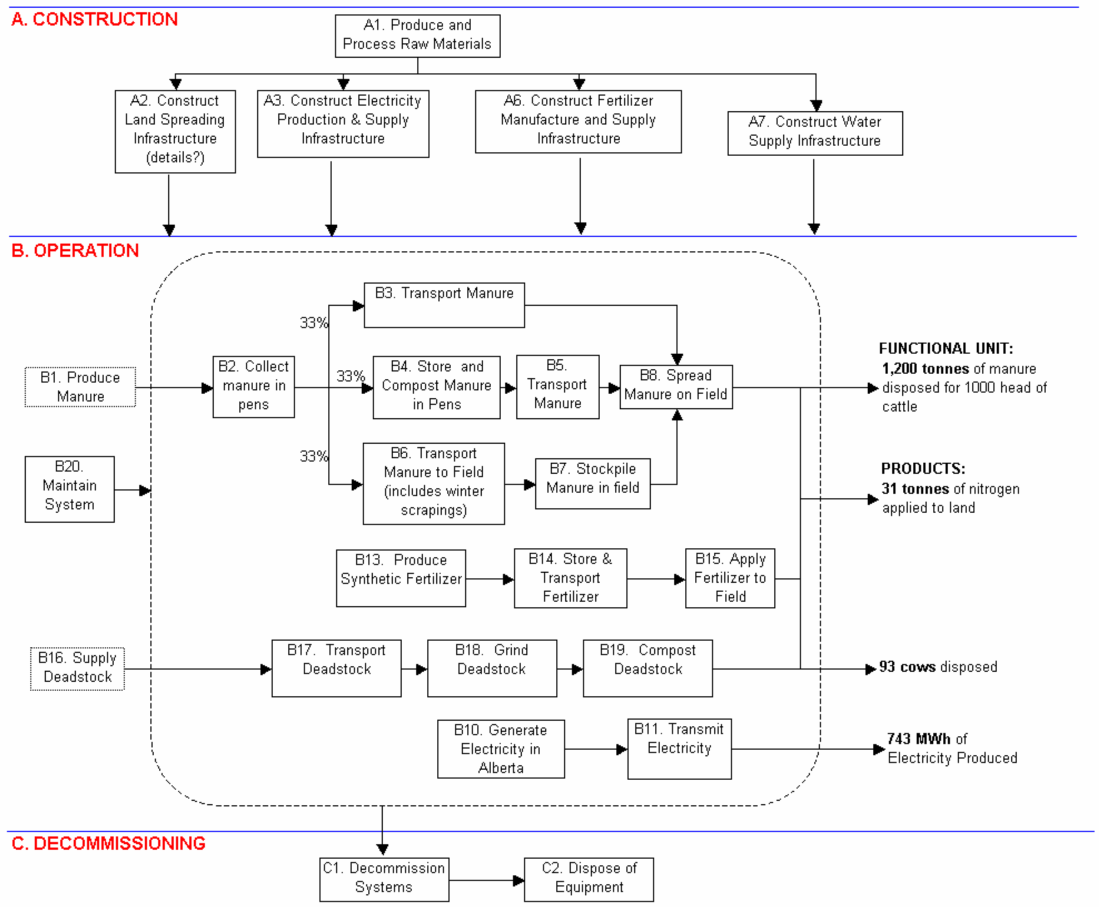

Figure 2.2: Life-Cycle Activity Map of Current Practice

2.3 Evaluation Criteria

Table 2.3 lists the factors identified by the project participants as highest importance to the primary audiences at this time. These factors are used as the evaluation criteria for the LCVA and therefore define the outputs of the assessment.

Table 2.3 Evaluation Criteria and Associated Indicators

Evaluation Criteria	Indicators
Economic viability	o Payback o Return on investment o Net present value o Operability[A]
Environmental sustainability	o Life-cycle GHG emissions o Energy consumption o Pathogens o Nutrient contamination o Deadstock disposal
Community impacts	o Odour o Traffic o Rural development opportunities[A]

[A] Were not quantified within the current LCVA due to time and data constraints

3.0 Inventory Assessment

The inventory assessment involves three steps: 1) data collection, 2) data assessment, and 3) summary. The inventory assessment is completed for each of the indicators identified in the scoping exercise.

The data collection was completed using multiple sources of information. The primary source of information was the project participants, Highmark Renewables and the Alberta Research Council. The information supplied by these sources is specific to the IMUS pilot project and current feedlot operations. This information was supplemented, and compared to varying degrees, against additional information collected from publicly available sources. The data sources for each unit process are summarized in Appendix A and Appendix B.

The following sections summarize the results of the inventory assessment for the economic, environmental and community impact indicators.

3.1 Economic Indicators

3.1.1 Financial Indicators

The financial analysis of the IMUS focused on two separate sizes of operations. First, an analysis was completed based on the 7,500 head demonstration project currently under construction at Highland Feeders. Second, an analysis was completed for a future scaled-up IMUS plant, which is able to handle the manure from 30,000 head of cattle. The analysis entailed construction of a financial model based on data provided by Highmark Renewables and the Alberta Research Council. Confirmation of the validity of the inputs was not completed at this time.

Table 3.1 summarizes some of the key financial inputs to the model. Table 3.2 summarizes the model outputs or results of the financial assessment.

Table 3.1 Inputs for the Financial Assessment of IMUS

Model Input	Units	Demonstration Project	Future Project
Project Size	animals	7500	30,000
Revenues			
Power Generation	kW	760	3040
Electricity Selling Price[A]	per kWh	\$0.091	\$0.091
Feedlot Price	per kWh	\$0.100	\$0.100
Manure Handling Cost Savings	\$/animal	\$4	\$4
Biofertilizer produced[B]	tonnes	5000	20000
Bio-fertilizer price			
Year 1	\$/tonne	5	5
Year 2	\$/tonne	25	25
Year 3	\$/tonne	40	40
Year 4	\$/tonne	50	50
Year 5-20 price inflation		2%	2%
Expenses			
Plant Price[C]		\$6,804,675	\$10,804,675
Shareholder Equity		\$1,950,000	\$5,402,338
Grants		\$3,254,675	\$0
Amount Financed		\$1,600,000	\$5,402,338
Financing rate		6.50%	6.50%
Term	years	10	10
Natural gas cost	\$/GJ	5.5	5.5
Employee salary and benefits	per year per person	\$50,000	\$50,000
Number of employees		3.0	7.0
Plant maintenance	% of equipment costs[D]	3.00%	3.00%
Amount of chemical	Mt/day	2	8
Price of chemical	\$/Mt	\$130.00	\$130.00
G & A	% of revenues	4%	4%
Inflation (applied to expenses except natural gas)		2.0%	2.0%
Tax rate		17.0%	17.0%

[A] Includes potential credits or incentives (e.g. carbon credits or renewable power production incentives).

[B] Assumes 70% of the maximum potential for biofertilizer production will be sold.

[C] Many parts of the IMUS demonstration plant are currently sized for a 30,000 head plant (currently, loading and centrifuge operations only run about 8 hours per day). Therefore, the additional plant costs for a 30,000 head facility are estimated to be limited to an additional \$2 million for power generation (taking max power output from 1MW to 3MW) and \$2 million in digester capacity.

[D] Equipment costs estimated to be 70% of total plant price. Assumes 10% of total costs for engineering and 20% for contingency.

Table 3.2 IMUS Financial Outputs

Model Output	Demonstration Project	Future Project
Project Net Present Value	-$829,000	$23,100,000
Rate of Return on Shareholder Investment	5.1%	17.2%
Payback on Shareholder Investment	15 years	7 years

The results of the financial assessment show that the IMUS demonstration plant is not economically viable to repeat, but with financial assistance, provides low, but positive returns for Highmark Renewables while they further develop the technology.

A future 30,000 head IMUS project, however, is expected to be economically viable. The difference between the two project types is primarily due to the estimated plant capital costs. For a new 30,000 head IMUS, the plant price is estimated to be $10.8 million, whereas the 7,500 head demonstration IMUS will cost approximately $6.8 million, a 60% improvement in capital cost per head of cattle. This is primarily due to the fact that much of the infrastructure within the demonstration plant is only being used for about 8 hours per day (e.g. loading and centrifuge operations). Increasing the operation of this equipment has the potential to increase plant capacity to up to 30,000 head of cattle with no changes to much of the installed equipment. The major additions required are $2 million for additional generators (taking max power output from 1MW to 3MW) and $2 million for an expansion in digester capacity.

Further analysis of the economic inputs to the model revealed several key factors contribute to the financial viability of the projects. Figure 3.1 presents the results of a sensitivity analysis whereby the inputs to the 30,000 head project were varied by 25%, and then the variation on the project's net present value were measured.

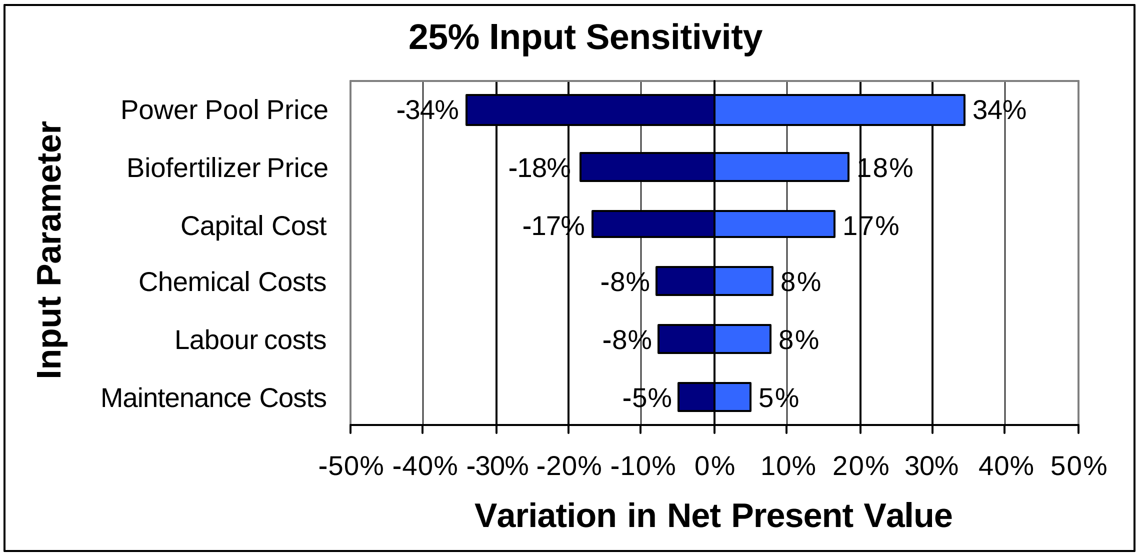

Figure 3.1: Financial Analysis Sensitivity Results (Future Project)

As Figure 3.1 demonstrates, the three financial parameters with the largest impact on the financial viability of the projects are: 1) the selling price of electricity, 2) the selling price of biofertilizer, and 3) the plant capital cost. In the opinion of the authors, these parameters also have relatively high uncertainty at this point of technology development than the other parameters listed in Table 3.1. Therefore, further work is required to prove the viability of these three economic factors in particular.

Further analysis of the price of electricity demonstrated that if the price for electricity was assumed to be $60 / MWh and $130 / MWh[1] instead of $91 / MWh (including all financial incentives and GHG credits), the project's economic viability will be affected considerably, as shown in Table 3.3.

Table 3.3 Affect of Electricity Price on Economics of a Future Project

	$60 / MWh	$91 / MWh	$130 / MWh
Project Net Present Value	$12,400,000	$23,100,000	$36,700,000
Rate of Return on Shareholder Investment	9.8%	17.2%	26.1%
Payback on Shareholder Investment	12 years	7 years	5 years

---

[1] Anticipated price for future biogas powerplants. [Li 2004]

3.1.2 Operability

The scoping exercise identified operability as another economic indicator needing to be assessed.

At this time, the IMUS pilot plant is not yet operational and so no information on the operability of the plant was available.

Reporting on the operability of IMUS should be considered in future work.

3.2 Environmental Indicators

3.2.1 Life-Cycle GHG Emissions

Emissions resulting from human activities, particularly the burning of fossil fuels, are substantially increasing the atmospheric concentrations of several important greenhouse gases, especially carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These increases are enhancing the greenhouse effect, resulting in an overall average warming of the Earth's surface. If emissions continue according to current trends, the temperature increase projected during the current century is expected to have a dramatic impact on the Earth's climate system, resulting in more extreme precipitation events over many areas and consequential flooding, increased risk of drought over most continental interiors, increasing rates of biodiversity loss, and especially rapid change in the Arctic. [IPCC 2001a,b]

To assess the life-cycle GHG emissions of the IMUS compared with the current practice, a spreadsheet model was created. This model quantifies the GHG emissions from each unit process within the boundaries of each system based on the disposal of manure from 1000 head of cattle for 1 year.

A summary of key assumptions for the model is listed in Section 2.1 while the complete input data for the model is presented in Appendix A and Appendix B.

The system boundary for the GHG assessment includes the operational processes unique to each system (shown in Figures 2.1 and 2.2). Construction and decommissioning processes are not included as it is assumed they play a relatively small role in the life-cycle GHG emissions. This is due to the fact that for power plants, construction emissions account for less than 0.05% of the life-cycle GHG emissions [McCulloch 2003]. Combine this with the fact that there are construction and decommissioning emissions in both systems (ie. both systems require equipment for manure handling, power generation, fertilizer production and deadstock disposal) and, therefore, the incremental difference is considered to be small compared to the level of effort required to quantify the GHG emissions from these sources.

The results of the life-cycle GHG emission inventory are presented in Tables 3.4 and 3.5 and graphically represented in Figure 3.2.

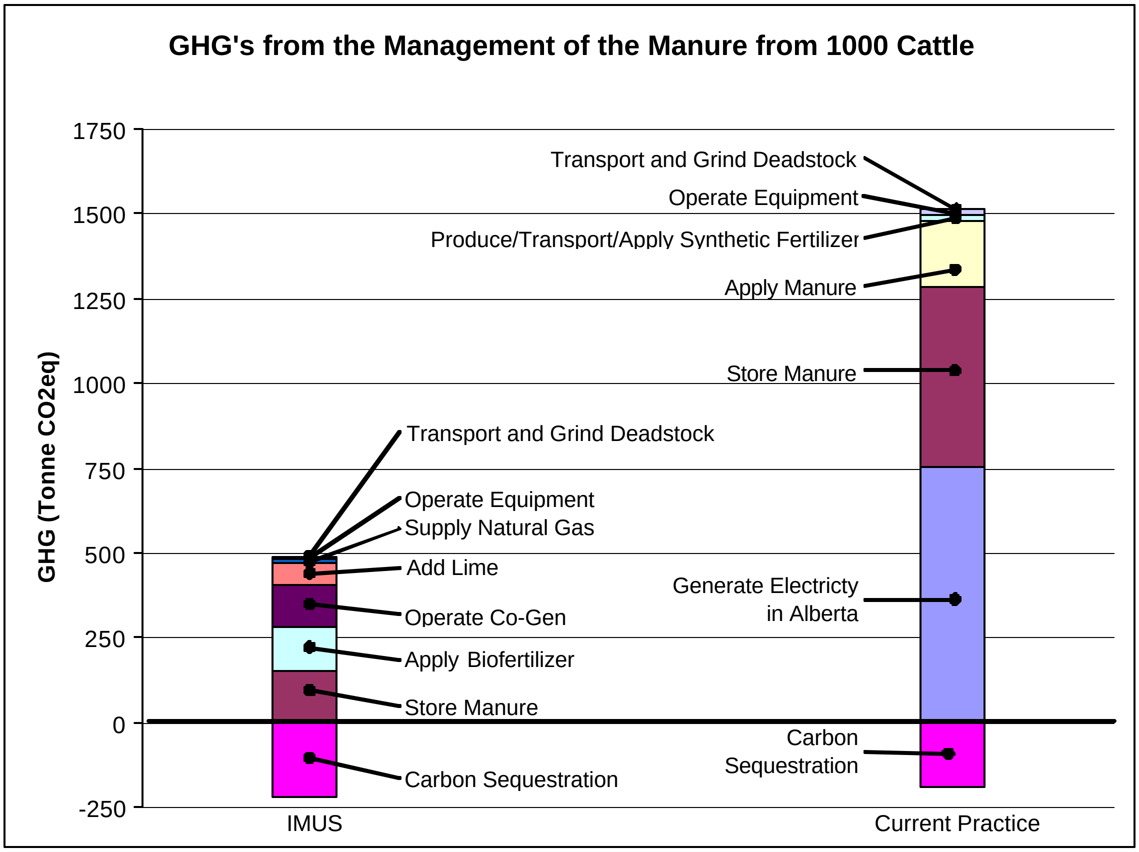

Figure 3.2: GHG produced from both manure management systems.
*Note: only a small amount of synthetic fertilizer is used in the base scenario.

Table 3.4 GHG Emissions Produced from IMUS

Unit #	Unit Process	Tonne CO_2eq / 1000 cattle per year
B1-B4	Store Manure	152
B2,3,4	Operate equipment	8.9
B8	Supply natural gas[A]	12
B9	Operate co-gen unit[B]	123
B16,17	Transport and Grind Deadstock	0.3
B24	Transport biofertilizer	1.9
B25	Apply biofertilizer	126
B28	Add lime	65
	Gross GHG Emissions	**489**
	Carbon sequestration	-222
	Net GHG Emissions	**267**

[A] Natural gas supplement is used during peak times to maximize the economic return of the plant. The engine in the IMUS demonstration project has been sized to accommodate this extra electricity production. Future plants could be sized to run only on biogas.

[B] Emissions from the combustion of natural gas and biogas (excluding carbon emissions from the biogas).

Table 3.5 GHG Emissions Produced from Current Practice

Unit #	Unit Process	Tonne CO_2eq / 1000 cattle per year
B1-B8	Store Manure	531
B2,3,4,5,6	Operate equipment	15
B8	Apply manure	194
B10	Generate electricity in AB	754
B17,18	Transport and Grind Deadstock	0.3
B13	Produce synthetic fertilizer[A]	6.1
B14	Transport synthetic fertilizer	0.2
B15	Apply synthetic fertilizer	12
	Gross GHG Emissions	**1,494**
	Carbon sequestration	-189
	Net GHG Emissions	**1,305**

[A] 4.8 tonnes of synthetic fertilizer (urea) are used.

The results show that the IMUS reduces life-cycle GHG emissions considerably when compared to the current practice (267 tpy vs. 1,305 tpy). This is primarily due to 3 factors:

1. Biogas electricity generation vs. average electricity generation in Alberta (619 tpy difference)
2. Manure storage time / emissions – 2 months vs. 6 months (379 tpy difference)
3. Spreading of biofertilizer vs. manure and synthetic fertilizer (80 tpy difference)

These factors, along with a few others, are described below. It should be noted that at this time there is high uncertainty regarding the GHG emissions from manure storage, and spreading of the various fertilizers. This is due to the complexities with estimating biological emissions, particularly from one specific case to another.

The highest single contributor to the GHG emissions in the Current Practice system is from providing electricity from the Alberta power grid. This electricity production accounts for approximately 50% of the gross emissions in the Current Practice. Since electricity generation from biogas is considered to be carbon neutral, the IMUS creates 619 tonnes CO_2eq fewer emissions than the grid average electricity in the current practice. This comparison includes the upstream GHG emissions for the coal and natural gas resource sectors. The IMUS plant is estimated to reduce direct powerplant emissions by 631 tpy (per 1000 head of cattle).

A 378 tonne of CO_2eq reduction occurs due to differences in the amount of CH_4 and N_2O emissions during manure storage in the pens. In the IMUS case, manure spends 66% less time in the pens than with the current practice and it is assumed this results in 66% fewer GHG emissions. At this time, there is little data to support the assumption that GHG emissions are directly proportional to manure residence time and so there is high uncertainty with the actual emission reduction in this area.

There are approximately 80 tonnes more CO_2eq. emissions (from N_2O) from the application of manure and synthetic fertilizer in the Current Practice case compared to the application of biofertilizer in the IMUS case. This is due to the fact that the application of biofertilizer was assumed to release 30% fewer emissions than the application of manure. This assumption is based on three studies that have indicated a range of 20 to 50% fewer N_2O emissions from a variety of digested manures when compared with the associated raw manure. The application of synthetic fertilizer only contributes a fraction to the emissions due to its small volume.

Emission reductions through soil carbon sequestration was calculated based on the amount of carbon from manure and biofertilizer that will remain in the soil 50 years after application. The carbon sequestration for IMUS is 7% higher than with the current practice since the carbon in biofertilizer is more stable than raw manure [Li 2004]. This equates to 33 tonnes CO_2eq more carbon sequestration with the IMUS system than in the Current Practice system.

Lime is added to the liquid streams at IMUS. The production of lime is an energy intensive operation, thus the life-cycle emissions for the production of lime were considered. Lime contributes approximately 13% of the gross emissions for IMUS or 65 tonnes CO_2eq.

The production, transportation and use of synthetic fertilizer create about 18 tonnes of CO_2eq. per year. About 5 tonnes of urea is added to the Current Practice in order to provide an equivalent amount of nitrogen to the soil as the IMUS case provides.

Overall, manure and deadstock handling contributes only a small portion of the total GHG emissions. Manure and deadstock handling is the activity of collecting and transporting manure and deadstock. The emissions occur from the combustion of diesel fuel in the trucks and tractors used. In this area, IMUS creates 4.5 tonnes CO_2eq. less than the Current Practice due mainly to the lower water content of biofertilizer when compared with manure.

Sensitivity Analysis

Three separate sensitivity analyses were performed on the emissions inventory.

Emission Sensitivity #1: Increased Biofertilizer Distribution

The Biofertilizer Distribution Sensitivity assumes that the current practice of spreading manure on surrounding fields provides little value when applied to the field and thus does not need to be replaced when it is diverted to the IMUS plant. This is true of situations where manure is over-applied to the lands directly surrounding the feedlots, thus eliminating any usefulness for the added nutrients and organic matter that comes from the manure. The biofertilizer is assumed to be transported during the return trip of a truck already delivering feed to the feedlot.

Table 3.6 shows the emissions associated with the sensitivity analysis. The net emissions from IMUS have decreased by about 1.4% (due to reduced truck use) and the net emissions from the Current Practice have increased by 27% (due to a greater amount of synthetic fertilizer).

Table 3.5 Sensitivity Analysis #1 – Net GHG Emissions (t CO_2eq.)

	IMUS	Current Practice
Base Case	267	1,305
Sensitivity Analysis	265	1,594

The results of this sensitivity analysis show that if bio-fertilizer from IMUS can be used to offset current applications of synthetic fertilizer, the emission reduction potential of the IMUS can be improved by 290 tpy. It should be kept in mind that this is only true for cases where the IMUS manure was previously over-applied to the fields surrounding the feedlot.

Emission Sensitivity #2: Less Carbon Sequestration

There is currently high uncertainty in estimating the amount of carbon sequestration for both systems investigated. The carbon from IMUS biofertilizer is known to be more stable than carbon from manure [Li 2004]. In the the base case, 18% of carbon from biofertilizer was assumed to remain in the soil 50 years after application, compared to 11% of the carbon from manure in the Current Practice.

Within this sensitivity, it was assumed that only 14% of the biofertilizer carbon remains in the soil as soil organic matter after 50 years. This is considered to be a conservative assumption based on research that indicates biofertilizer carbon is more stable than manure carbon.

Table 3.6 shows the emissions associated with this sensitivity analysis. The net emissions from IMUS have increased by approximately 18% since less carbon is now sequestered in the soil. However, the total system emissions from the IMUS are still less than 25% of the total system emissions for the Current Practice.

Table 3.6 Sensitivity Analysis #2 – Net GHG Emissions (t CO_2eq.)

	IMUS	Current Practice
Base Case	267	1,305
Sensitivity Analysis	316	1,305

Emission Sensitivity #3: Increased Rate of N_2O Emission

There is relatively high uncertainty regarding the rate of N_2O emissions during manure storage due to a lack of available data. Therefore, a sensitivity on the N_2O emission rate during manure storage was performed.

In the base scenario, it is assumed that, on average, the total emissions, as estimated within Canada's GHG Inventory, occur during the normal 6 months of residence time that manure spends in the feedlot pens. It was also assumed that if the residence time were reduced to 2 months, the related N_2O emissions would be reduced by 66%.

In the N_2O Emission Rate Sensitivity, a more conservative assumption (from the perspective of the IMUS project) is used. In this scenario, it is assumed that the shorter residence time in the IMUS case results in a 33% reduction in emissions. Therefore, the reduction in N_2O emissions from manure storage is half of the amount estimated in the base case.

Table 3.7 shows the results of this sensitivity on life-cycle emissions. The net emissions from IMUS have increased by 50% overall, but remain 70% less than the current practice (compared to 80% less in the base case).

Table 3.7 Sensitivity Analysis #3 – Net GHG Emissions (t CO_2eq.)

	IMUS	Current Practice
Base Case	267	1,305
Sensitivity Analysis	418	1,305

Emission Sensitivity #4: 100% Biogas

The IMUS demonstration project has been designed to have approximately 17% of the fuel supply for cogeneration come from natural gas (by energy content). It is possible, however, for the fuel supply to be 100% biogas. This sensitivity explores the changes to net GHG emissions that would occur if no natural gas was used to supplement fuel supply within the IMUS.

If IMUS were to use 100% biogas, as opposed to 83% biogas and 17% natural gas, more manure would be required to be input to the system. The amount of cattle required to produce enough manure to operate with 100% biogas is 1,166 head of cattle compared to the base case of 1000 head of cattle.

The management of more manure increased emissions for both the IMUS and Conventional Practice in the categories of Store Manure, Operate Equipment, Transport and Grind Deadstock. There was also an emission increase associated with the production of lime since more was required for operation of IMUS. And there was an emission increase from the transportation and application of synthetic fertilizer and biofertilizer.

For IMUS, the emissions from the supply and combustion of natural gas were eliminated since there was no use of natural gas. As a result, emissions from operation of the co-generation unit were decreased. Production of electricity in Alberta in the Conventional Practice remained the same since the same amount of electricity was produced in both cases.

Table 3.8 shows the new emissions associated with IMUS and the Conventional Practice when 100% biogas is used to produce the same amount of electricity as in the base case. The emission reductions associated with the IMUS project become even greater when 100% biogas is used, as opposed to a mixture of biogas and natural gas.

Table 3.8 Sensitivity Analysis #4 – Net GHG Emissions (t CO_2eq.)

	IMUS	Current Practice
Base Case	267	1,305
Sensitivity Analysis	202	1,373

3.2.2 Energy Input

Total energy input to equivalent systems is an indicator of overall efficiency. The overall energy input of each system was quantified using the life-cycle model described above. The inventory assessment not only looked at the amount of energy being input, but the type of energy as well. The results of the analysis are shown in Table 3.6.

Table 3.8 Energy Input to Each System

Energy Type	**IMUS**	**Current Practice**
Coal	0 GJ	8,944 GJ
Natural Gas	1,305 GJ	2,628 GJ
Diesel	127 GJ	63 GJ
Biomass[A]	13,060 GJ[B]	13,060 GJ
Total Energy Input	**14,500 GJ**	**24,700 GJ**

[A] Using a value of 10,883 kJ/kg for the total amount of energy potential in dry manure

[B] From the total energy potential of the manure 7,833 GJ is utilized as biogas

The IMUS uses 42% less total energy than the current practice. In addition, 85% of the energy for the IMUS comes from a renewable energy base. This is an indication that the IMUS case, with a high portion of renewable energy and lower overall energy use, is inherently more sustainable than current practices over the longer term.

3.2.3 Pathogens

Pathogens are disease-causing organisms. Manure can potentially contain some of the more common food-borne pathogens: enteric viruses, E. coli, cryptosporidium, salmonella, brucella, listeria, clostridium, cyclospora, and chlamdiya. The spread of pathogens from manure to water and food is of concern. The LCVA considered the general impact the IMUS has on manure pathogens.

Pathogens are 99% eliminated within the anaerobic digester and a lime treatment is used to destroy the remaining pathogens [Li 2004]. This virtually eliminates the potential risk of manure based pathogens from harming people or animals.

Testing may be warranted to confirm the IMUS anaerobic digester performs as expected and does truly eliminate all of the pathogens within the manure.

3.2.4 Nutrient Contamination

Nutrient contamination is the build up of excessively high amounts of nutrients (e.g. nitrogen, phosphorus, potassium, heavy metals) in land, surface water, or groundwater causing them to become polluted. Excessive amounts of nutrients can, for example, cause the eutrophication of lakes and reservoirs, or degradation of soil. [Wolf 2003]

The amount of nutrient contamination that will occur in each system is not easily determined. This is because the flow of nutrients is dependent on numerous factors including application method and amount, soil conditions, and weather. Therefore, it is not possible to quantify the precise difference in nutrient contamination between the two systems without defining a specific application scenario. This was not within the scope of this project; however, an indicator for the amount of nutrient contamination in each system is the total amount of nutrients applied in each system.

In the base case, there are close to the same amounts of nutrients being applied to the land. This is due to the fact that IMUS has over 90% nutrient recovery in its system and the IMUS solids are applied to the same land that the manure was previously.

However, there are cases where there is currently over-application of manure to the lands surrounding feedlots due to the relatively high cost to transport the manure. The result is much higher application of nutrients to this area, and a much greater potential for nutrient contamination than occurs in the IMUS case. This is because in the IMUS case, nutrients are only applied in the quantities desired via biofertilizer due to the lower cost of transporting biofertilizer versus manure.

An example of the difference in nutrient application for the Increased Biofertilizer Distribution sensitivity is summarized in Table 3.7. In this scenario, there is 29 tonnes of excess nitrogen applied to lands surrounding the feedlot per year for 1000 head of cattle. This is due to the fact that in this scenario, it is assumed that there is more than enough nitrogen applied to these lands given the over-application of manure from the feedlot. Therefore, introduction of an IMUS plant in this case would reduce the chance of nutrient contamination from the field where the manure was previously applied. This conclusion may or may not apply to other nutrients, depending on the current levels and conditions of application.

Table 3.9 Total Nutrients Applied in Increased Biofertilizer Utilization Sensitivity

Material	Location of Application	Total Mass (tonnes)	Carbon (tonnes)	Nitrogen (tonnes)	Phosphorus (tonnes)	Potassium (tonnes)
IMUS						
Biofertilizer	Regional	907	336 ± 7.4	31 ± 0.09	25 ± 0.05	20 ± 0.08
Current Practice						
Manure	Close to Feedlot	1200	468 ± 11.4	29 ± 0.06	24 ± 0.05	28 ± 0.08
Chemical Fertilizer (Urea)	Regional	76	0	31	0	0

Further analysis of the impact of over-application of manure should be undertaken to better understand the downstream implications of land spreading of manure.

It should be noted that the actual use of biofertilizer from the IMUS is somewhat uncertain at this time, as the IMUS pilot plant is not yet operational. Further study of the actual use of the IMUS biofertilizer and the subsequent displacement of other products should be investigated once the operation has been established.

3.2.5 Deadstock Disposal

The disposal of cattle is a growing issue for feedlots and ranches. With the current atmosphere in the Canadian cattle industry (border closures due to the emergence of several cases of BSE), there is a need to increase the industry's capacity to dispose of cattle in an economic manner that does not create environmental contamination.

At this time, research into the alternative disposal methods of deadstock was not investigated in detail; however, it was identified that the IMUS has the potential to create value (electricity and biofertilizer in particular) from the disposal of deadstock as opposed to simply composting deadstock. Using IMUS for the disposal of deadstock has the potential to reduce the environmental impact of composting them.

3.3 Social Indicators

3.3.1 Odour

The odour created by cattle feedlots is one of the highest public concerns with such operations. General observation from feedlot operators is that most of the manure odour emissions occur during spreading. While IMUS will not eliminate odour, it does offer the ability to reduce manure odour considerably as both the solid and liquid outputs of the system have virtually no odour emissions. [Kotelko 2004]

Odour emissions from manure within the feedlot is also expected to decrease with the IMUS since manure is expected to have less residence time within the feedlot pens. With conventional land spreading practices, manure has an average residence time of 6 months whereas for the IMUS, the manure is expected to sit for only 2 months, on average, before entering the digester. The precise reduction in odour emissions has not been quantified at this time.

3.3.2 Traffic

Travel on rural roads is a necessity of everyday life for the people who live and work in rural areas. Traffic on these roads also has negative impacts, namely the potential for collisions, stirring up of dust, vehicle emissions and noise.

The amount of traffic that is created by intensive livestock operations is a concern for many nearby residents. This is particularly true during the spring and the fall when most of the manure spreading occurs.

IMUS has the potential to reduce truck traffic around the feedlot by reducing the volume and weight of solids that need to be removed from the feedlot. Figures 3.2 and 3.3 show the estimated number of trips and total truck kilometers for each manure management option.

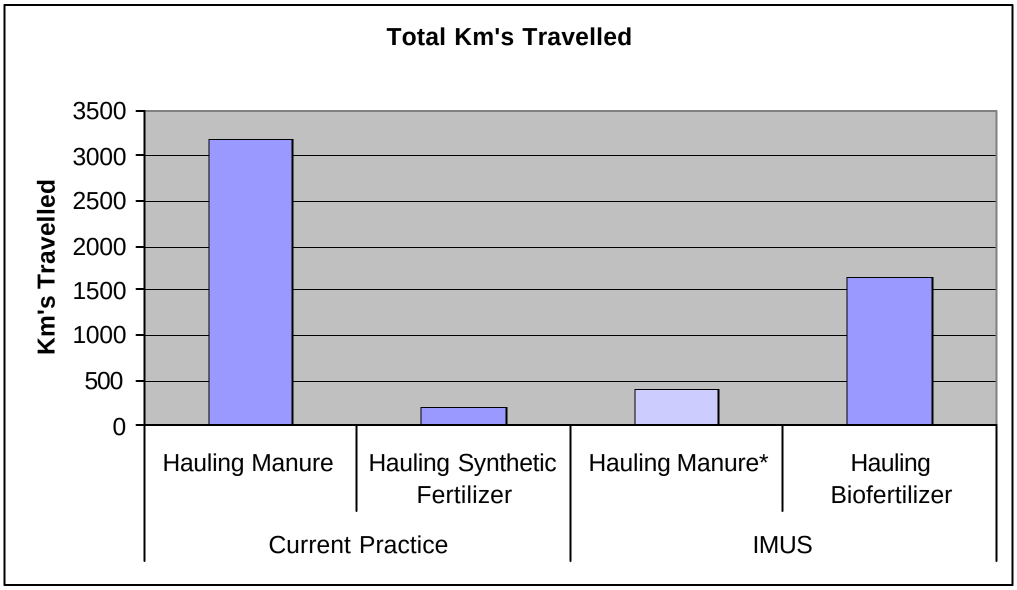

Figure 3.2: Total km's traveled per 1200 tonnes of manure utilized.
*Full trip within feedlot

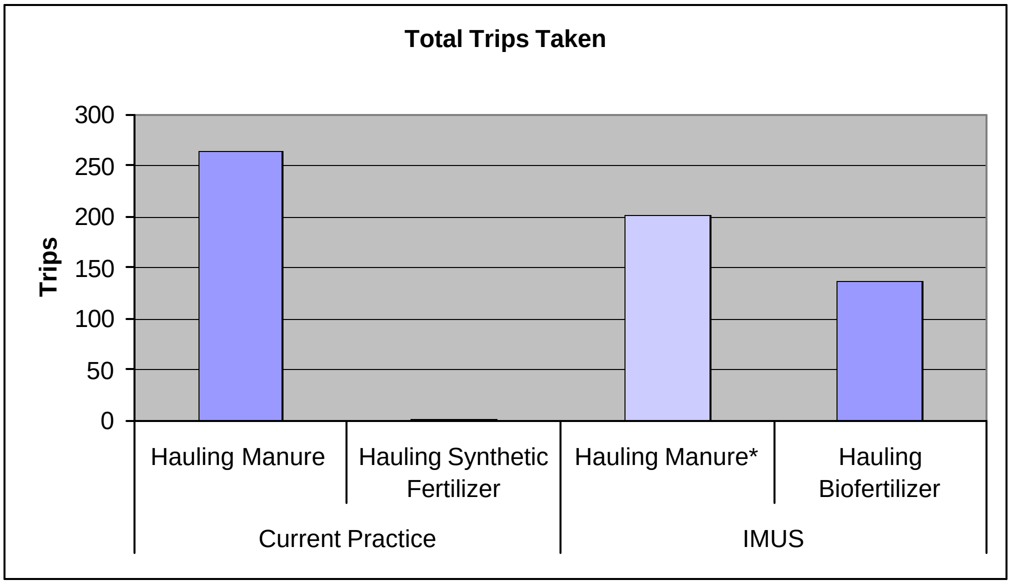

Figure 3.3: Total trips taken per 1200 tonnes of manure utilized.
* Full trip within feedlot.

The results show that the IMUS does reduce the number of truck trips by almost 50%, or 130 trips mainly due to the fact that the hauling of manure in the IMUS case is contained within the feedlot and never reaches public roads. Approximately 200 trips within the feedlot are not counted for the purpose of quantifying traffic impacts.

The total truck kilometers traveled has been decreased by more than 50%, or approximately 1,730 km per year since the biofertilizer is transported the same distance to the fields as raw manure and its weight is decreased by 30%. Again, hauling manure in the IMUS case is not used in this calculation since these trucks never leave the feedlot.

It is not possible to draw further conclusions regarding the impact the IMUS will have on the impact of traffic volumes on safety and resident quality of life without further information. More detailed analysis requires information on both the time of year for these trips of interest, and the existing traffic volumes on the roads of interest. This would allow better determination of the direct impact of the IMUS on traffic volumes both close to the feedlot, and on other rural roads.

The analysis also considered the impacts of the 'Increased Biofertilizer Distribution' sensitivity analysis on truck traffic. In this sensitivity, the biofertilizer was assumed to displace synthetic fertilizer at farms in the surrounding area as opposed to being spread on the fields surrounding the feedlot. The biofertilizer is transported to farms via return trips on the trucks that deliver feed to the feedlot; hence there will be no increase in truck traffic to the feedlot.

In the sensitivity, IMUS will not have any trips beyond the confines of the feedlot or any kilometers on public roads, compared to the Current Practice, which will have about 270 trips for a total of 3,400 km.

3.3.3 Rural Development Opportunities

It is expected that the development of IMUS plants will positively impact the rural economy through construction and operation employment and supply, as well as increased stability of livestock operations. Specific information regarding the amount of impact the IMUS plants are expected to have on rural economies was not available at the time of writing this report. Further work in this area could potentially improve the case for support of the IMUS from various organizations.

4.0 Conclusions

Based on the areas that were investigated within this LCVA, the IMUS clearly demonstrated its potential for producing positive societal impacts. At this stage of IMUS development, however, a number of key questions remain regarding the economic viability and operability of the system. It is expected that these questions will be answered through operation of the IMUS pilot plant currently being constructed near Vegreville, Alberta and further business development activities.

This section summarizes the results of the analysis, barriers to further implementation, emerging opportunities for IMUS developers' and areas of further investigation.

Primary Results

A 30,000 head IMUS project appears to be economically viable if three key factors are met: 1) a power purchase price of $90 / MWh on average; 2) a capital cost under $11 million; and 3) an established biofertilizer price of $50 / tonne. Further analysis of the IMUS financial parameters is required to obtain greater certainty of its financial viability.

The IMUS reduces the environmental life-cycle impact of greenhouse gas emissions on the global climate by approximately 1,040 tonnes CO_2eq per year per 1000 head of cattle when compared with the current practice of land spreading (an 80% reduction from current levels). 619 tpy is due to displacement of grid average electricity and is considered to have high certainty. (The IMUS plant is estimated to reduce direct powerplant emissions by 631 tpy.) The remaining emission reductions are accomplished through reducing direct methane and nitrous oxide emissions during manure storage (by reducing storage times), by reducing nitrous oxide emissions during fertilizer spreading, and several other lower impact reasons.

The emission reductions from changes in manure storage and spreading are considered to have high uncertainty at this point due to limitations with quantifying GHG emissions reductions as a result of changes in agricultural practices. Even with more conservative assumptions regarding GHG emissions during manure storage and fertilizer spreading, the IMUS still has 900 tpy fewer GHG emissions than the Current Practice (a 70% reduction from current levels).

It was also found that the introduction of an IMUS plant into a feedlot has many other environmental benefits. It reduces the extraction and consumption of non-renewable resources by displacing an estimated 11,700 GJ of coal and natural gas per 1000 head of cattle per year. It virtually eliminates potentially harmful pathogens within manure. And it has the potential to eliminate the environmental hazards associated with the disposal of deadstock. In areas where there is over-application of manure to the land, IMUS can also decrease the potential for nutrient contamination in the land, and ground and surface water.

IMUS also reduces the impact of feedlot operation in several non-environmental areas. It was found that IMUS reduces manure odour, lessens truck traffic on public roads, and is expected to contribute to rural economic diversification.

For feedlots, IMUS can both diversify income and skills, and possibly allow for greater expansion of the feedlot operations, due to a reduction in the feedlot's overall environmental and societal impact. These results provide the added benefit of contributing to increased economic stability for feedlots.

For rural communities located near intensive livestock operations, the IMUS provides an opportunity for improved quality of life through odour reduction, a reduction in harmful pathogens and nutrient contamination in the surrounding environment, safer roads, and economic diversification.

The benefits from IMUS could be further enhanced in cases where manure is currently over-applied to lands surrounding the feedlot. In these cases, the IMUS biofertilizer can be used to displace the use of synthetic fertilizers in other fields. This has the combined effect of reducing the potential for nutrient contamination surrounding the feedlot, reducing GHG emissions by an additional 290 tpy, and reducing road traffic by about 270 trips or 3,400 km per year for every 1000 head of cattle. It should be noted that this is dependent on the ability to sell biofertilizer to local farmers.

The benefits of IMUS could also be further enhanced by utilizing 100% biogas within the plant, as opposed to a mixture of biogas and natural gas.

Barriers to Implementation

Throughout the analysis, the project team has attempted to identify potential barriers to the further implementation of IMUS. These include:

- Capital funding (e.g. access to financing)
- Required size (e.g. requires feedlots to grow to a particular size before implementing IMUS)
- Expertise (e.g. in the areas of design, construction, operation)
- Awareness and knowledge (e.g. availability and benefits of the technology)
- Permitting (e.g. particularly for generators > 1MW)

It is expected that given the considerable potential for the multiple societal benefits of IMUS, there will be strong justification for institutions (e.g. governments and industry organizations) to support its development by addressing several of the barriers to its implementation.

Emerging Opportunities

During the research, several emerging opportunities for the future development of the IMUS were identified. These include:

- Possibility of net metering for the feedlot
  - Net metering is not widely used in Canada at this time, but within a few years, it is expected to be available in various jurisdictions. By using net metering for a feedlot / IMUS combination, it is likely to provide a higher effective price for a portion of the electricity generated.
- Possibility of incentives for distributed generation
  - Generation from distributed sources throughout the electricity grid (e.g. locating generators close to loads) offers many advantages to the operation of the grid, not the least of which is lower electrical transmission losses. At this time, there are few direct incentives for distributed generation, but as the value of these plants becomes increasingly acknowledged, there is an increasing potential for incentives for distributed generation. At some point in the future, operators of IMUS may be rewarded for creating distributed generation.
- IMUS as a low cost heat source
  - The generation of electricity within IMUS also creates heat that can be used in external processes. The pilot plant currently being constructed by Highmark Renewables does not use this excess heat, and therefore, there is an opportunity to leverage this low cost heat source in other uses that create additional value for the feedlot.
- Disposal of other waste materials
  - The primary function of IMUS is the disposal of manure. Within the process, there is also the potential to dispose other materials such other organic wastes. This could create value for both the producers of the waste and the IMUS operators who can generate electricity and other useful products from the waste. This opportunity is limited by the constraints of the anaerobic digester and the overall IMUS capacity. Care should be taken to ensure the digester is able to operate effectively. Excess capacity of the IMUS system may not be available until all of the manure from the feedlot can be processed, or for a defined period of time when the full capacity of the plant is not being used. Caution should also be taken to ensure the waste materials would not result in hazardous emissions.
- Environmental marketing – Green Power sales, creating a Green Feedlot certification
  - A growing market for environmentally preferred products exists. The environmental benefit of IMUS provides operators the potential to market its products as environmentally friendly or ‘green’. Environment Canada’s Environmental Choice Program has defined

    criteria for Renewable Low-impact Electricity. Upon preliminary review of the criteria, it is expected that the electricity from an IMUS plant would be eligible for certification. The IMUS may also contribute to the environmental marketing of a particular intensive livestock operation.

- Value added products – e.g. gardening materials from solids output.
    - There are opportunities to increase the value of the outputs before they are sold. The principle opportunity that has already been identified in this area is the conversion of solids from the IMUS to seedling pots. Other opportunities may also exist and could be explored further.

Further Work

It is possible to investigate the triple-bottom-line impact of the IMUS in greater detail in the future if needed. This may include the impact that the IMUS could have on the livestock industry, regional economies, quality of life for surrounding residents, and the productivity of the surrounding ecosystem.

Further investigation and analysis of IMUS financial parameters is required to establish greater certainty of its financial viability. The areas that were identified as having relatively high uncertainty and very high importance to project economics are: 1) the power purchase price, 2) the biofertilizer price, and 3) the plant capital costs.

Reporting on the operability of IMUS should be considered in future work.

At this time, there is high uncertainty with the assumptions regarding potential GHG emission reductions from manure storage and fertilizer spreading. These two areas account for nearly 45% of the difference in life-cycle GHG emissions between the systems. Further investigation in this area is warranted to increase the certainty of the overall life-cycle analysis.

It should be noted that the actual use of biofertilizer from the IMUS is somewhat uncertain at this time, as the IMUS pilot plant is not yet operational. This LCVA assumes that the biofertilizer displaces the manure that is currently applied to the land surrounding the feedlot. Further study of the actual use of the IMUS biofertilizer and the subsequent displacement of other products should be investigated once the market has been initially established.

The overall impact of changes in trucking patterns requires further investigation. Initial results show that the total number of truck trips from the feedlot should lessen due to the reduced volume of biofertilizer when compared with manure. The impact that these changes will have on road safety and quality of life for local residents is unknown, as this will depend on factors such as existing traffic volumes on these roads.

Closing

Overall, the initial assessments of the IMUS are very positive. Further investigation and demonstration is needed in some key areas to confirm the actual life-cycle performance of the operations, but early indications point towards improved triple-bottom-line performance of manure management for intensive livestock operations.

Appendix A: IMUS Unit Process Descriptions

The following are the descriptions of the unit processes for the IMUS system of manure management. The activity map for this system can be found in Figure 2.1.

Name:	Produce Manure	**UP #:**	B1
Description:	The amount of manure produced per 1000 cattle per year.		
Background:	An average of 1200 tonnes of dry weight manure is produced from 1000 cattle in one year.		
Assumptions:	▪ Cattle produce approximately 1.2 tonnes of manure per animal per year, dry weight [Kotelko 2004] ▪ Total weight of raw (wet) manure input for IMUS is 4444 tonnes with a solids content of 27%. [Jenson 2004]		

Name:	Collect and Transport Manure	**UP #:**	B2, B3, B4
Description:	Manure is collected in pens and transported to IMUS.		
Background:	The manure collected for IMUS using tractor and the box scrapings are transported to IMUS using a truck and loaded into the hopper. IMUS will replace the need to compost manure in the pens. Winter scrapings may also supply some of the manure used at IMUS. Practices will be adjusted to accommodate the plant.		
Assumptions:	▪ The distance manure will need to be transported is estimated at 1 km. ▪ Truck time for transport is 24.7 hr / year per 1000 head. ▪ Tractor time for transport is 63.9 hr / year per 1000 head.		

Name:	Store Manure	**UP #:**	B1 – B4
Description:	The storage of manure in the pen releases methane (CH_4) and nitrogen in the form of ammonia (NH_3) and nitrous oxide (N_2O).		
Background:	Emissions from manure storage occurs continuously, but the level of emissions during a particular period are dependent on a number of factors including weather, composition, moisture content, amount of handling and the way it is stored. The level of emissions follows standards outlined by Environment Canada in Canada's Greenhouse Gas Inventory. Some assumptions needed to be made about the differences in emissions for each case as		

	supporting data was not available.
Assumptions:	▪ Typical waste management systems in the GHG Inventory are representative of the waste management system at Highland Feeders. ▪ A 66% reduction of storage time in the pens for IMUS manure compared to conventional land spreading manure (2 months vs. 6 months storage) reduces the emissions by 66%.

Name:	Produce Biogas	**UP #:**	B5, B6, B7
Description:	Manure is mixed with water to create slurry for the anaerobic digester. The resulting biogas is cleaned before it can be used to generate power.		
Background:	Energy consumed for these unit processes do not use external energy and all emissions are accounted for with the production of heat and electricity.		
Assumptions:	▪ Manure input to IMUS is 27% total solids [Jenson 2004] ▪ No gas is vented from the anaerobic digester. ▪ The gas output composition by mass of the anaerobic digester is (34.2% CH_4, 3.2% N_2, 0.82% O_2, 0.01 H_2S and 61.8% CO_2) [Jenson 2004]		

Name:	Supply Natural Gas	**UP #:**	B8
Description:	Natural gas is used to supplement biogas to produce more electricity when economics dictate.		
Background:	Natural gas can be used in addition to biogas to produce more electricity if economical. An average was calculated using a sample “best” month and a sample “worst” month for total electricity output and required gas consumption. The life cycle of natural gas from exploration, production and transmission is used to calculate the amount of greenhouse gas emissions for the natural gas used at IMUS.		
Assumptions:	▪ Average electricity production from IMUS is 850 kW. ▪ Biogas can supply an average of 746 kW. ▪ Average supply of natural gas is 1167 MJ/hr. ▪ Average fuel mixture is 83.5% biogas and 16.5% natural gas by energy content. ▪ Upstream production of 100 m^3 of natural gas results in 33.641 kg CO_2eq. [Monenco 1994]		

Name:	Operate Co-Gen Unit	**UP #:**	B9
Description:	The Jenbacher generator combusts biogas and natural gas to produce electricity and heat.		

Background:	Biogas is considered climate neutral with respect to any CO_2 emissions so CO_2 emissions from the combustion of biogas are not counted but emissions from CH_4 and N_2O are included. CO_2eq emissions produced from the combustion of the natural gas supplement to the biogas are counted as well.
Assumptions:	▪ The combustion of 1 m^3 of natural gas produces 1902 kg of CO_2eq. [Environment Canada 2004] ▪ The combustion of one GJ of biogas produces 323 grams of CH_4 and produces 0.5 grams of N2O [Danish Gas Technology Centre, National Environmental Research Institute 2000].

Name:	Convert Power	**UP #:**	B10
Description:	Efficiency of transformer power conversion.		
Background:	The losses were interpolated for a 4000 kVA transformer operated at 850 kVA.		
Assumptions:	▪ 9.125 kW losses at 850 kVA load (98.9% efficient). [Pioneer Transformers 2004] ▪ The average power consumed at the plant is 178 kW. [Jenson 2004] ▪ Power consumption varies based on temperature. The average was calculated using a yearly average temperature in Vegreville of 2.3°C [Environment Canada – Meteorological Service of Canada 2004]		

Name:	Transmit Electricity	**UP #:**	B11
Description:	Efficiency of power transmission.		
Background:	Transmission losses are not considered since the electricity will be used locally. Losses considered are from electricity distribution on local distribution lines.		
Assumptions:	Distribution losses are 3.55% (96.45% efficient). [Jem Energy 2004]		

Name:	Prepare Water for Hopper Mixture	**UP #:**	B13, B14
Description:	The water mixed with the manure in the hopper has to be pH adjusted and heated.		
Background:	Energy used to heat the hopper water is waste heat from the generator. The pH adjustment utilizes exhaust gases. Excess waste heat is not currently used for another process, but users may be added in the future.		
Assumptions:	IMUS produces 898 kW of thermal power. [Jenson 2004]		

Name:	Maintain System	**UP #:**	B20
Description:	The system maintenance requirements to maintain operation of IMUS.		
Background:	Operating costs were supplied that included day to day costs like oil changes and banking for long term items such as rebuilds, etc. [Jenson 2004]		
Assumptions:	▪ Operability and maintenance can not be quantified until the plant is fully operational		

Name:	Operate Centrifuge	**UP #:**	B21
Description:	The centrifuge separates the solids from the liquids.		
Background:	The liquids are separated into a liquid stream and the solids are separated into a solid stream.		
Assumptions:	▪ Solids have a water content of 70% (30% solids) [Jenson 2004]		

Name:	Solid Stream	**UP #:**	B22, B23
Description:	Preparation of biofertilizer.		
Background:	Solids are collected and enriched with nitrogen from the wastewater and phosphorus is removed from the solids. Lime is added to assist in this process. See unit process B28 for more information on the addition of lime.		
Assumptions:	▪ 90% nutrient recovery. [Li 2004] ▪ A total of 19.5 tonnes/day (dry weight) of biofertilizer is produced. [Jenson 2004]		

Name:	Store and Transport Biofertilizer	**UP #:**	B24
Description:	Biofertilizer that is temporarily stored on site until it is transported to the land application area.		
Background:	The biofertilizer will be transported to the land surrounding the feedlot for application.		
Assumptions:	▪ Estimated transport distance is 6 km. ▪ A 22 tonne truck is used for transport. ▪ Truck time for transport is 85.9 hr / year per 1000 head. ▪ Tractor time for transport is 2.6 hr / year per 1000 head.		

Name:	Apply Biofertilizer to Land	**UP #:**	B25
Description:	Field application of biofertilizer and carbon sequestration.		
Background:	Application of biofertilizer produces N_2O emissions and emissions from combustion of diesel for the spreading. Carbon savings from soil carbon sequestration is the		

	amount of carbon from the biofertilizer that will remain in the soil 50 years after application. The amount of dry solids in the biofertilizer was used to calculate the amount of carbon that will remain in the soil.
Assumptions:	▪ Truck time for transport is 7.2 hr / year per 1000 head. ▪ Tractor time for transport is 10.0 hr / year per 1000 head. ▪ N_2O is released from application of manure [Environment Canada GHG Inventory 2004] ▪ See Environment Canada's GHG Inventory 2004, pg. 109 for N_2O emission factors. ▪ Application of biofertilizer releases 30% fewer N_2O emissions than the application of manure as fertilizer. (Based on results from Chatigny 2003, Peterson 1999, Sommer 2002) ▪ Cattle manure contains 37% carbon. ▪ 18% of the carbon will remain in the soil as soil organic matter after 50 years. [Li 2004] ▪ 907 tonnes of dry weight biofertilizer (at 30% solids) is produced from 1200 tonnes of dry weight manure [Jenson 2004]

Name:	Collect Liquids, and Recover N and P	**UP #:**	B26, B27
Description:	Separation of liquids from the solid stream for nutrient extraction and reuse.		
Background:	Liquids are collected from the centrifuge. The liquids contain nitrogen, which is recovered for enrichment of the biofertilizer solids. The output water is recycled and treated for re-use in the anaerobic digester and any excess water is stored in the lagoon. See unit process B13 and B14 for the water treatment and unit process B30 for water storage.		
Assumptions:	All excess output water is stored in the lagoon.		

Name:	Add Lime and Wood Ash	**UP #:**	B28
Description:	Lime is added to solid and liquid streams.		
Background:	Lime used in IMUS is primarily for phosphate removal from manure effluents. It also acts as coagulant for suspended solids settling. In addition, it helps increase pH for ammonia removal and for pathogen reduction.		
Assumptions:	▪ The lifecycle of lime was calculated using lime with a 97% lime content, $Ca(OH)_2$. [World Resource Institute 2004] ▪ The lime used for IMUS testing is 97% high calcium hydrated lime and 95% high calcium hydrated lime is the preference for future applications. [Zeng 2004]		

Name:	Store Lagoon Water	**UP #:**	B30
Description:	An on-site lagoon is used for the storage of rainwater runoff from the feedlot and to store excess IMUS water.		
Background:	Lagoon water supplies the water needs of IMUS and acts as storage for any excess IMUS water. The main purpose of the lagoon is retention of rainwater runoff from the feedlots. Lagoon water is also used for irrigation of nearby feed crops.		

General Assumptions

Reference	Assumption	Source
Diesel Emissions – Truck	2.94 kg CO_2eq / litre of diesel for Mobile 5A truck	U.S Department of Energy, 1991
Diesel Emissions - Tractor	2.64 kg CO_2eq / litre of diesel for Duluchi tractor	U.S Department of Energy, 1991
Truck fuel consumption	27.3 L/hr	Kotelko 2004
Tractor fuel consumption	40.9 L/hr	Kotelko 2004
Truck for stockpiling	Truck capacity of 22 tonnes	Kotelko 2004
Truck for direct spreading	Truck capacity of 15 tonnes	Kotelko 2004

Appendix B: Current Practice Unit Process Descriptions

The following are the descriptions of the unit processes for the Current Practice system of manure management. The activity map for this system can be found in Figure 2.2.

Name:	Produce Manure	**UP #:**	B1
Description:	The amount of manure produced per 1000 cattle per year.		
Background:	A total of 1200 tonnes of dry weight manure is produced from 1000 cattle in one year.		
Assumptions:	▪ Cattle produce approximately 1.2 tonnes of manure per animal per year, dry weight [Kotelko 2004] ▪ Total weight of raw manure is 4444 tonnes at 27% solids. [Jenson 2004]		

Name:	Collect Manure in Pens	**UP #:**	B2
Description:	Manure is collected in the pens using a tractor and truck.		
Background:	Manure is typically collected in the pens twice a year and enters three streams of manure management defined as: direct spreading, composting manure in pens and stockpiling in the field. It is estimated that each stream utilizes one third of the collected manure. 1. Direct Spreading – Manure is collected in the pens and loaded into trucks and transported to the field where it is spread directly from the truck. 2. Composting Manure in Pens – This stream is the same as direct spreading except that manure is composted in the pens and turned with a tractor twice in six months. The volume is reduced and the composted manure is spread directly to the field. 3. Stockpiling in the Field – Manure is collected in the pens and loaded into trucks and transported to the field. Manure is stockpiled until the appropriate time of year for application is reached. Final spreading of the manure requires loading of a direct spreading truck for field application.		
Assumptions:	▪ Field is 6 km from feedlot and takes 1 hour for a round trip [Kotelko 2004] ▪ 15 tonne trucks are used for direct spreading [Kotelko 2004] ▪ 22 tonne trucks are used for stockpiling [Kotelko 2004]		

	▪ Truck and tractor times are estimated from a spreadsheet compiled for the cleaning of one pen containing 600 tonnes of raw manure. [Kotelko 2004] ▪ Tractor time for manure collection is 22.3 hours / year per 1000 head.

Name:	Transport Manure to Field	**UP #:**	B3
Description:	Trucks are loaded with manure and the manure is transported to the field for direct spreading.		
Background:	Diesel is consumed by two activities; loading the truck with the tractor and transport of the manure by truck. A truck with a capacity is 15 tonnes and direct spreading capabilities is used.		
Assumptions:	▪ Truck time for manure transport is 39.1 hr / year per 1000 head. ▪ Tractor time for manure transport is 10.5 hr / year per 1000 head.		

Name:	Compost Manure in Pens	**UP #:**	B4, B5
Description:	Manure is composted in pens for six months to reduce volume and odour and then spread directly on the field.		
Background:	Turning of the compost is required several times per year. Time required for composting include compost turning with a tractor, truck loading and truck transport to field.		
Assumptions:	▪ Truck time for composting is 24.4 hr / year per 1000 head. ▪ Tractor time for composting is 18.1 hr / year per 1000 head.		

Name:	Stockpile Manure in Field	**UP #:**	B6, B7
Description:	Manure is transported to field to be spread later at appropriate times.		
Background:	Winter pen scrapings are part of this manure stream and require extra winter preparation such as snow plowing and field access considerations. Pen scrapings in winter and scrapings from other times of the year that cannot be spread directly are stockpiled in the field until they can be spread. Spreading takes place in spring after snowmelt and in autumn.		
Assumptions:	▪ Winter transport includes snow plowing and field access. ▪ Truck time to stockpile is 50.4 hr / year per 1000 head. ▪ Tractor time to stockpile is 14.1 hr / year per 1000 head.		

Name:	Spread Manure on Field	**UP #:**	B8
Description:	Manure is spread using a truck and incorporated with a tractor.		
Background:	Manure from the three streams is spread on the field using a 15 tonne truck and incorporated using a tractor. N_2O is released during spreading. Carbon savings from soil carbon sequestration is the amount of carbon from the manure that will remain in the soil 20 years after application. The amount of dry weight manure was used to calculate the amount of carbon that will remain in the soil.		
Assumptions:	▪ Only small amounts of CH_4 are released from manure during spreading and not calculated. ▪ See Environment Canada's GHG Inventory 2004, pg. 109 for N_2O emission factors. ▪ Truck time for spreading is 66.7 hr / year per 1000 head. ▪ Tractor time for spreading is 83.6 hr / year per 1000 head. ▪ Cattle manure contains 37% carbon. [Li 2004] ▪ 11% of the carbon will remain in the soil as soil organic matter. [Li 2004]		

Name:	Store Manure	**UP #:**	B1 – B8
Description:	The storage of manure in the pen releases methane (CH_4) and nitrogen in the form of ammonia (NH_3) and N_2O.		
Background:	Emissions during manure storage occurs continuously, but the level of emissions during a particular period are dependent on a number of factors including weather, composition, moisture content, amount of handling and the way it is stored. The level of emissions follows standards outlined by Environment Canada in Canada's Greenhouse Gas Inventory. Some assumptions needed to be made about the differences in emissions for each case as supporting data was not available.		
Assumptions:	▪ Typical waste management systems in the GHG Inventory are representative of the waste management system at Highland Feeders.		

Name:	Generate Electricity in Alberta	**UP #:**	B10
Description:	Average generation of electricity in Alberta on the provincial grid.		
Background:	The equivalent amount of electricity generated in Alberta is 808,000 kWh including the transmission losses calculated in unit process B11. Using the breakdown of electricity sources in Alberta the GHG emissions produced are 754,000 kg CO_2eq.		

Assumptions:	▪ Alberta Electricity; 67% Coal, 29% Natural Gas, 2.7% Hydro, 0.6% Wind, 1.2% Biomass, 0.03% Other [Jem Energy 2003] ▪ 933 kg CO_2eq / MWh (includes upstream fuel supply emissions) [Monenco 1994] ▪ 887 kg CO_2eq / MWh [Environment Canada GHG Inventory 2004, Statistics Canada 2003]

Name:	Transmit Electricity	**UP #:**	B11
Description:	The average transmission and distribution efficiency in Alberta.		
Background:	In order to deliver an equivalent amount of electricity in each system, any transmission efficiencies need to be taken into account. For the grid average electricity, the average transmission losses need to be accounted for.		
Assumptions:	▪ 92% efficient (4.45% transmission losses + 3.55% distribution losses) [Jem Energy 2004]		

Name:	Produce Synthetic Fertilizer	**UP #:**	B31
Description:	Production of urea fertilizer for land application.		
Background:	The amount of CO_2eq for the production of one tonne of urea was calculated using data from Environment Canada and The Untied Nations. See Appendix C for the calculation. A nitrogen balance was used to calculate the required amount of urea fertilizer required for land application.		
Assumptions:	▪ 1284 kg CO_2eq per tonne of urea produced. [United Nations], [Environment Canada 2001] ▪ 1.4 tonnes of urea is required to supplement the manure spreading to provide an equivalent amount of nitrogen as in the biofertilizer from IMUS.		

Name:	Store and Transport Fertilizer	**UP #:**	B32
Description:	Transportation of urea from source to location of application.		
Background:	Urea fertilizer is produced in Redwater, AB and requires transport to a fertilizer distribution centre in Vegreville, AB (approx 100 km). Urea is transported by 22 tonne truck for this unit process. Transport by rail to Vegreville could reduce emissions, but truck transport would be required for final transport to the field.		
Assumptions:	▪ Truck time for transport is 2.5 hr / year per 1000 head. ▪ Tractor time for transport is 0.1 hr / year per 1000 head. ▪ The average distance fertilizer will be transported is 100km.		

Name:	Apply Fertilizer to Land	**UP #:**	B33
Description:	Field application of urea fertilizer.		
Background:	Application of synthetic urea fertilizer produces N_2O emissions and emissions from combustion of diesel.		
Assumptions:	▪ Truck time for transport is 0.2 hr / year per 1000 head. ▪ Tractor time for transport is 0.3 hr / year per 1000 head. ▪ See Environment Canada's GHG Inventory 2004, pg. 109 for N_2O emission factors.		

Name:	Supply Deadstock	**UP #:**	B16, B17, B18
Description:	Deadstock supply per day.		
Background:	On average 2 animals are disposed of per day. Current practice is disposal of the animal at a rendering plant. Other practices include composting the animal. Emissions are produced from transportation of deadstock (B17). No emissions were calculated for the operation at the rendering plant.		
Assumptions:	▪ All animals will be disposed at a rendering plant. ▪ Truck time for transport is 0.75 hr / year per 1000 head.		

General Assumptions

For a list of general assumptions for truck and tractor use and emission factors, see Appendix A.

Appendix C: Production of Urea

The production of pure ammonia consumes 34.5 GJ of energy (24.5 GJ for use as a feedstock and 10 GJ for combustion to produce heat for the process) [United Nations 1998]. Both the feedstock and the fuel are assumed to be natural gas. The natural gas feedstock is converted to CO_2 in the chemical process and no CH_4 is vented during ammonia production.

Table C1 is the emissions for the combustion of natural gas as a fuel. The chemical conversion of the CH_4 feedstock to ammonia only uses the CO_2 emissions from Table C1 since this value is from a carbon balance of methane.

Table C1: Emissions from Industrial Combustion of Natural Gas

Natural Gas	CO_2 (g/m^3)	CH_4 (g/m^3)	N_2O (g/m^3)
Industrial Combustion	1891	0.037	0.033

[Environment Canada 2004]

The calculation of emissions is as follows:

<u>Natural Gas as a Feedstock for Ammonia Production</u>
24.5 GJ (natural gas) = 660 m^3 (natural gas), produces ***1,247 kg CO_2eq/tonne NH_3***,

<u>Natural Gas for Combustion to Provide Heat for Ammonia Production</u>
10 GJ (natural gas) = 269 m^3 (natural gas), produces 509 kg CO_2, 0.21 kg CO_2eq (CH_4), 2.8 kg CO_2eq (N_2O) = ***512 kg CO_2eq/tonne NH_3***

<u>Natural Gas as a Feedstock + for Combustion</u>
Total Feedstock + Combustion NG = 1247 kg CO_2eq + 512 kg CO_2eq = ***1,759 kg CO_2eq/tonne NH_3***

CO_2 emissions from the production of ammonia are used to produce urea. However, these emissions should not be subtracted from the total since the CO_2 is only temporarily stored in the urea and emitted upon application of the fertilizer.

<u>Natural Gas Production</u>
To make a complete life cycle evaluation, the energy and emissions from the production of natural gas is also included. The production of natural gas produces 33.6 kg CO_2eq per 100 m^3 of natural gas [Monenco 1994], or **312.1 kg CO_2eq** for a total of 929 m^3 of natural gas.

The total emissions to produce 1 tonne of ammonia is ***2,071 kg CO2eq/tonne NH_3***.

<u>Production of Urea</u>

The production of one tonne of urea requires 0.570 tonnes of NH_3, 0.750 tonnes of CO2 and 396 MJ of electricity [United Nations 1998]. The CO_2 input is recycled from the emissions from the production of NH3 and should not be double counted. The higher range of the electricity input was used since electricity powers the CO_2 compressor. The emissions for the production of electricity in Alberta is 933 kg CO_2eq/MWh. [Jem Energy 2003]

0.570 t NH3 = (0.57*2071) = 1180 kg CO_2eq
396 MJ = (396MJ * 0.278 kWh/MJ) = 110 kWh
= (0.110 MWh * 933 kg CO_2/MWh) = 102 kg CO_2eq

The total emissions to produce 1 tonne of urea is ***1,284 kg CO_2eq***.

References

Chantigny, M.H., P. Rochette, D.A. Angers, D. Côté, D. Massé, G. Bélanger. 2003. "Anaerobic digestion of pig slurry : Energy and environemtnal (carbon and nitrogen) assessments following field application of digested slurry." Agriculture and Agri-Food Canada, Sainte-Foy, QC. February.

Environment Canada – Meteorological Service of Canada. 2004. Climate Data Online, http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html

Environment Canada. 2004. Canada's Greenhouse Gas Inventory, 1990-2002. Ottawa, ON. ISBN 0-660-18894-5.

Feng, Y. X. Li, 2001. An analytical model of soil organic carbon dynamics based on a simple "hockey stick" function. Soil Science. ISBN: 166:431-440.
Intergovernmental Panel on Climate Change (IPCC). 2001a. "Summary for Policymakers, A Report of Working Group I of the Intergovernmental Panel on Climate Change." Available at www.ipcc.ch.

Intergovernmental Panel on Climate Change (IPCC). 2001b. "Summary for Policymakers, Climate Change 2001: Impacts, Adaptation and Vulnerability, A Report of Working Group II of the Intergovernmental Panel on Climate Change." Available at www.ipcc.ch.

Jem Energy. 2004. "A Study on the Efficiency of Alberta's Electrical Supply System." Project # CASA-EEEC-02-04 for the Clean Air Strategic Alliance (CASA). Edmonton, AB.

Jenson, Earl. 2004. Personal Communication. Alberta Research Council. Ph: (780)-632-8321

Kotelko, Mike. 2004. Personal Communication. Highmark Renewables. Ph: (780) 768-2466

Kristensen, G Jensen, Jan - Danish Gas Technology Centre and Nielsen, Malene & Illerup, Jytte Boll - National Environmental Research Institute, 2000, Emission Factors for Gas Fired CHP Units < 25 MW. Denmark. Appendix A.

Li, Xiaomei. 2004. Personal Communication. Alberta Research Council. Ph: (780) 450-5290.

Monenco Agra Inc,1994. Development of a Database for Full Fuel Cycle Emissions from Electric Power Generation in Alberta, Appendix G.

Peterson, S. O. 1999. "Nitrous Oxide Emissions from Manure and Inorganic Fertilizers Applied to Spring Barley." Journal of Environmental Quality. Vol. 28, no. 5, Sept.-Oct. 1999.

Pioneer Tranformers Ltd. 2004. "Transformer Test Report" for Padmount Transformer, ONON, 4000 kVA.

Sommer, S.G., S.O. Peterson, J.B. Moller. 2002. "A new model for calculating the reduction in greenhouse gas emissions through anaerobic co-digestion of manure and organic waste." Danish Institute of Agricultural Sciences.

Statistics Canada. 2003. Electricity Power Generation, Transmission and Distribution – 2001. Cat. No. 57-2002-XIB. Ottawa.

United Nations Environment Programme. 1998. Part 1. The Fertilizer Industry's Manufacturing Processes and Environmental Issues., Paris, France. ISBN: 92-807-1640-9

Wolf, B.; Snyder, G. 2003. Sustainable Soils, The Place of Organic Matter in Sustaining Soils and Their Productivity. The Haworth Press. New York, USA.

World Resources Institute. 2004. World Business Council for Sustainable Development - Greenhouse Gas Protocol Initiative – Calculation tools, http://www.ghgprotocol.org/standard/tools.htm

Zeng, Le. 2004. Personal Communication. Alberta Research Council. Ph: (780)-632-8463. December 13, 2004.

The Pembina Institute is an independent non-profit research, education and advocacy organization that promotes environmental, social and economic sustainability through the development of practical solutions for businesses, governments, individuals and communities. The Pembina Institute provides policy research leadership on climate change, energy policy, green economics, renewable energy, and environmental governance, as well as extensive formal and public education programs. More information about the Pembina Institute is available at www.pembina.org.

Pembina Institute
for Appropriate Development