University of Alberta

Design and Demonstration of a High Throughput DNA Tracking System for Genetic Improvement and Brand Verification in the Canadian Beef Industry

by

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Abstract

The Canadian beef industry today is challenged to adapt to climate change and to produce quality beef more efficiently, using fewer resources and with less impact to the environment. Competing protein sources have integrated their supply chains and applied genetic selection to increase efficiencies dramatically. Creating vertical linkage and increasing integration in the Canadian beef supply chain may be an opportunity to meet production challenges. A practical DNA tracking system was designed and demonstrated as a potential solution for the Canadian beef industry. High throughput SNP technology was used to create links between 1,237 feeder calves from multisire pastures, and their performance records, to their respective sires for the purpose of genetic improvement. Subsequent producer breeding decisions were based on Sire Production Summaries generated for their bulls. As an added value this system also delivers DNA traceability on beef products, enabling label verification and expansion into markets demanding traceability.

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Table of Contents

Chapter 1: Introduction **1**

1.1 Problem statement 1

1.2 Background 2

1.2.1 Industry structure 2

1.2.2 Fragmentation in the beef value chain 7

Chapter 2: Literature Review **14**

2.1 Challenges faced by the Canadian beef industry today 14

2.1.1 Competition for natural resources 14

2.1.2 Challenges of global climate change 15

2.1.3 Competition from other proteins 15

2.2 Opportunity presented by population growth 23

2.3 Vertical integration 23

2.4 Genetic improvement 26

2.5 Branded beef products 29

2.6 Existing traceability and vertical integration systems 33

2.6.1 Systems in the EU and Ireland 34

2.6.2 Systems in Japan and South Korea 36

2.6.3 Systems in Australia and New Zealand 36

2.6.4 Systems in the U.S. and Canada 37

2.7 Animal identification technology 39

Chapter 3: The Design and Demonstration of a DNA Tracking System for the Canadian Beef Industry **41**

3.1 Introduction 41

3.2 Hypothesis and research objectives 42

3.3 Project partners 43

3.4 Materials and methods 46

3.4.1 DNA sample collection 47

3.4.2 DNA extraction........49
3.4.3 Genotyping........49
3.4.4 Parentage verification........50
3.5 Results........51
3.5.1 Evaluation of DNAsampling technology for efficacy........51
3.5.2 Evaluation of genotyping technologies........52
3.5.3 Parentage calls........53
3.5.4 Generating sire commercial production summaries........53
3.5.5 Label verification........54
3.5.6 Errors........56
3.6 Discussion........56
Chapter 4: Future Efforts........64
Literature Cited:........67

List of Tables

Table 1: CanFax estimates of production cost for 100 kg of beef carcass weight in 2011 for 6 competitive beef production countries in the global market (CanFax 2013) 1

Table 2: Traits for which EPDs are available from the larger Canadian breed Associations 5

Table 3: Owner, location, and daily processing capacity (number of cattle) of the three largest and two midsized packing plants in Canada (CanFax, 2013)................................. 6

Table 4: The Possible Change Table for Canadian Angus EPDs indicates how much an EPD can change (plus or minus the EPD) based on its accuracy (CAA, 2013). 9

Table 5: The average price of several different cuts of beef, pork and poultry in 2009, 2010, 2011, 2012, and 2013, illustrating how much more expensive beef can be, depending on the cut, than other protein sources (Stats Canada, 2012)........................... 17

Table 6: The quality requirements for beef to qualify for marketing under the Certified Angus Beef branded program (Siebert and Jones, 2013).. 30

Table 7: SNP parentage verification genotypes at 10 loci for a calf and its 3 potential sires as an example of the process of sire verification, Sire 2 and Sire 3 both have 2 mismatches from the calf's genotype at loci AY939849 and AY856094 and at loci AY858890 and AY856094 respectively, Sire 1 qualifies to this calf with 0 mismatches and a 100 percent confidence.. 50

Table 8: A comparison of the ease and cost of using three different DNA sampling methods for live cattle, and three different DNA sampling methods for cut beef. 51

Table 9: Assessment of different DNA sampling technologies trialed in this project at the laboratory; hair samples and Allflex and Typifix tissue collection technologies were used to DNA live animals and the IdentiGEN scraper was used to DNA sample cut beef. These four technologies were assessed at the laboratory for DNA concentration, failure rates, processing time and ease of biobanking.. 52

Table 10: A comparison of the Infinium Whole-Genome Genotyping chemistry on the BovineSNP50 version 2C marker panel with the Illumina HiScan machine, using the

Sequenom MassARRAY, and using NGG by Eureka Genomics for cost, processing time, accuracy, DNA requirements and limitations of the technology. 53

List of Figures

Figure 1: A depiction of the different sectors of the Canadian beef industry and the flow of product down the production chain. 3

Figure 2: A comparison of two bulls' Weaning Weight EPDs (+57 and +69 respectively) and the expected difference in the average of their calves' weaning weights (12 lb) given the same opportunity to develop the trait. 4

Figure 3: CAA RFID Tag that fulfills the National animal identification and animal movement tracking requirements and also provides potential buyers a visual guarantee of a minimum of 50 percent Angus genetics (CAA, 2013). 12

Figure 4: The expected difference, 25 lb on average, at weaning for the progeny of two bulls with Weaning Weight EPDs differing by 25 lb (Bullock, 2009). 27

Figure 5: Greenhouse gas emissions for UK livestock industries, showing a reduction in environmental foot print for the dairy, sheep and pig industry between 1990 and 2012 (Gov.UK, 2013). 28

Figure 6: A HAB supplied Hero Burger label certifying the beef product as Angus based, raised without the use of added hormones, antibiotics, in an environmentally sustainable and humane manner, and as fully traceable. 31

Figure 7: The program schematic for a popular animal traceability system, TraceBack®, used in Irish livestock industries to link meat product from gate to plate (IdentiGEN, 2013). 35

Figure 8: A depiction of the Canadian beef industry sectors, the flow of product down the production chain, and the information that each sector participating in this DNA tracking system would provide. 42

Figure 9: A prototype of the Sire Production Summary that seed stock breeders and commercial producers participating in this DNA tracking system would receive, reporting the average performance of calves SNP parent verified to the sire, and the sire's Breed Association EPDs 47

Figure 10: The three animal DNA collection technologies that were assessed during the project, including hair root bulb (1), Typifix tissue collecting tags (2), and Allflex NextGen TSUs (3). 48

Figure 11: The three beef product sampling technologies assessed within this project, including the IdentiGEN meat scraper (1), plastic knives (2) and tongue depressors (3). 49

Figure 12: An example of a Sire Production Summary generated for producers participating in this demonstration of this DNA tracking system that outlines the average performance of two bulls for number of calves, carcass quality traits and feedlot growth for use in subsequent breeding decisions to drive genetic improvement for these traits. . 54

List of Abbreviations

AAA	- American Angus Association
AAFC	- Agriculture and Agri-Food Canada
AB	- Alberta
ABP	- Alberta Beef Producers
ADG	- Average Daily Gain
AgMRC	- Agricultural Marketing Resource Center
ALMA	- Alberta Livestock and Meat Agency
BC	- British Columbia
BIXS	- Beef Exchange Information System
BSE	- Bovine Spongiform Encephalopathy
BRD	- Bovine Respiratory Disease
BW	- Birth Weight
CAB	- Certified Angus Beef
CAA	- Canadian Angus Association
CBI	- Canada Beef Inc
CCA	- Canadian Cattlemen's Association
CCIA	- Canadian Cattle Identification Agency
CED	- Calving Ease Direct
CEM	- Calving Ease Maternal
CFIA	- Canadian Food Inspection Agency
CLIA	- Canadian Livestock Identification Agency
CPM	- Canadian Premium Meats
DNA	- Deoxyribonucleic Acid
EPD	- Expected Progeny Difference
EU	- European Union
FAO	- Food and Agriculture Organization of the United Nations
FAT	- Back Fat
FSEP	- Food Safety Enhancement Program
FSIS	- Food Safety Inspection Service
G	- Grams
HAB	- Heritage Angus Beef
HACCP	- Hazard Analysis Critical Control Point

ISAG	- International Society for Animal Genetics
KG	- Kilograms
LB	- Pounds
LIMS	- Laboratory Information Management System
MCOOL	- Mandatory Country Of Origin Labelling
NCE	- National Cattle Evaluation
NGG	- Next Generation Genotyping
NGS	- Next Generation Sequencing
PHAC	- Public Health Agency of Canada
ON	- Ontario
REA	- Rib Eye Area
RFI	- Residual Feed Intake
RFID	- Radio Frequency Identification
RFLP	- Restriction Fragment Length Polymorphism
SNP	- Single Nucleotide Polymorphism
STR	- Short Tandem Repeat
TESA	- The Environmental Stewardship Award
TSU	- Tissue Sampling Unit
UK	- United Kingdom
U.S.	- United States of America
USDA	- U.S. Department of Agriculture
VBP	- Verified Beef Production
WCRF	- World Cancer Research Fund
WW	- Weaning Weight
YW	- Yearling Weight

Chapter 1: Introduction

1.1 Problem statement

As a leading producer of safe, high quality beef the Canadian beef industry operates in a highly competitive world protein market, competing for market place with other countries including Argentina, Australia, Brazil, India, New Zealand, and the U.S. (Schroeder, 2003). The increasing value of the Canadian dollar, and high beef production costs have encouraged markets to substitute Canadian beef with beef coming from competing exporters or with other protein sources (Schroeder, 2003). Table 1 contains information on the cost of production per 100 kg of beef carcass weight in 2011 for several competitive beef producing countries.

Table 1: CanFax estimates of production cost for 100 kg of beef carcass weight in 2011 for 6 competitive beef production countries in the global market (CanFax 2013)

2011 Cost of Production Per 100 kg of Carcass Weight	
Mexico	$330
US	$404
Argentina	$411
Australia	$425
Canada	$487
Spain	$509

According to the information in Table 1, when compared to Mexico, the U.S., Argentina, and Australia, Canada was estimated to have one of the highest, second only to Spain, cost of beef production in 2011 (CanFax, 2013). This increase in production cost is attributed to several factors including higher livestock prices, higher energy prices which significantly affect the cost of fertilizer and transportation, land scarcity, and over capacity of U.S. feedlots which are a large market for Canadian feeder calves (Deblitz and Dhuyvetter, 2013).

Competitive markets and higher costs of production limit the profit margin on Canadian beef. The current structure of the Canadian beef industry, which comprises of several independent sectors, means that generally each sector conducts transactions for its own profitability, competing with other sectors within the industry for profit margin. This practice and the fragmented structure of the Canadian beef production chain have resulted in limited vertical integration within the industry. Lack of vertical integration poses several challenges to the beef industry; these are discussed in detail in Section 1.2.2. This project aims to provide solutions for these challenges.

1.2 Background

The Canadian beef industry is comprised of 68, 434 ranches that run a total of 13.54 million head of cattle, 5.58 million that are in Alberta, and contribute significantly, $33.75 billion in 2011, to the country's economy (Stats Can, 2013). In 2012 the industry produced 2.91 billion tonnes of beef; 58 percent of which was consumed nationally and 42 percent of which was exported, largely to the U.S. (CBI, 2013).

1.2.1 Industry structure

The Canadian beef production industry is comprised of 5 main sectors including purebred, or seed stock, breeders, commercial producers, the feedlot sector, packing plants, which are also called slaughter houses or abattoirs, and ultimately, the retail and food services sector. Figure 1 illustrates the industry structure and the flow of product between the different sectors of the Canadian beef production chain. Each sector is described in more detail below.

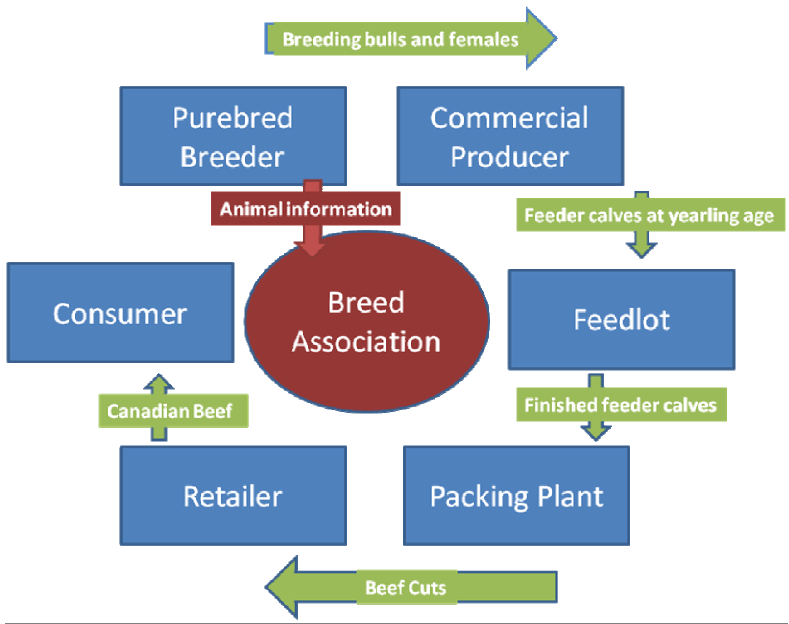

Figure 1: A depiction of the different sectors of the Canadian beef industry and the flow of product down the production chain.

1.2.1.1 The seed stock, or purebred, sector

The Canadian beef production chain begins with seed stock breeders who raise breeding animals for the rest of the industry. Typically, these breeders raise purebred animals and register their cattle with Breed Associations, recording pedigrees and performance information for selection of the best genetics with which to service the beef industry. Breed Associations are charged under the Canadian Animal Pedigree Act to maintain accurate animal pedigrees. The Pedigree Act is a federal statute established in 1905 that aims to support breed improvement and to protect persons who raise and purchase animals. It carries out these goals by helping to create Breed Associations that register and identify purebred animals. To protect those who raise and purchase purebred cattle, under the Act unregistered cattle cannot be marketed as purebred and registered animals must be transferred to the new owner within six months (AAFC, 2013).

The seed stock sector is where genetic improvement occurs in the value chain. Seed stock breeders drive genetic improvement by applying selection pressure for specific traits by selecting animals with proven superior genetic merit for those traits. Most Breed Associations provide their members with selection tools that identify animals with superior genetic merit by running genetic evaluations that apply pedigree, performance information, and estimates of heritability to generate genetic selection tools such as

Expected Progeny Differences (EPDs). EPDs are numeric estimations of the average expected difference in an animal's progeny for specific traits (Bullock, 2009; Vestal *et al.*, 2013). EPDs are used to fairly compare the genetic merit of animals raised in different environments. Figure 2 illustrates how EPDs are used in beef production systems. In this example the two bulls being compared differ in Weaning Weight EPD by 12 lb (EPDs are published in units of the trait that they are describing, in the case of weaning weight this is lb). Their EPDs predict that, when bred to similar females and given the same opportunity to develop weaning weight, the progeny from Bull B will weigh, on average, 12 lb more than the average progeny from Bull A.

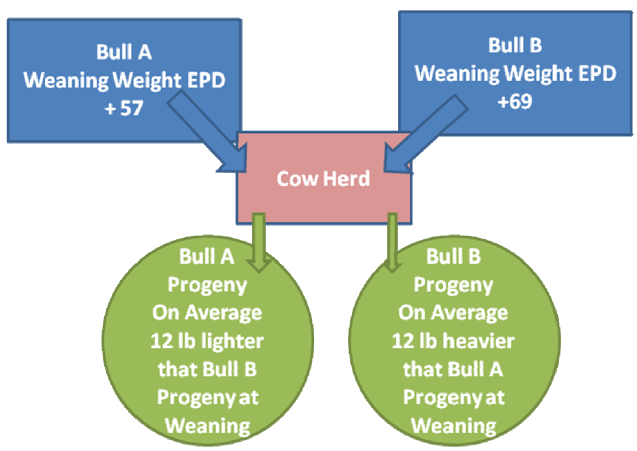

Figure 2: A comparison of two bulls' Weaning Weight EPDs (+57 and +69 respectively) and the expected difference in the average of their calves' weaning weights (12 lb) given the same opportunity to develop the trait.

Through their respective Breed Associations, EPDs are available on most seed stock animals for growth, fertility, and carcass quality traits (Garrick, 2011). Table 2 lists the traits some of the larger Canadian Breed Associations collect performance information on and report EPDs for. To varying degrees depending on the trait, Canadian seed stock breeders use EPDs and phenotypic observations to drive genetic improvement.

Table 2: Traits for which EPDs are available from the larger Canadian breed Associations

	Canadian Angus	Canadian Simmental	Canadian Hereford	Canadian Charolias	Canadian Limousin
# Calves registered in 2012	61,583	18,934	15,571	13,307	5,562
Birth Weight	x	x	x	x	x
Weaning Weight	x	x	x	x	x
Yearling Weight	x	x	x	x	x
Mature Weight		x	x		
Calving Ease	x	x	x		x
Stayability	x		x		x
Heifer Pregnancy	x				
Milk	x	x	x	x	x
Scrotal Size	x	x	x	x	x
Rib Eye Area	x	x	x	x	x
Marbling	x	x	x	x	x
Back Fat	x	x	x	x	x
Carcass Weight	x	x			x
Yield Grade	x			x	x
Feedlot Merit			x		
Gestation Length					x
Docility					x

As breeding stock are sold at yearling age, historically, this sector has focused primarily on driving genetic improvement for growth traits.

1.2.1.2 Commercial producers

Seed stock cattle, including breeding bulls and replacement females, are purchased by commercial producers who multiply these genetics generating feeder calves for consumption. Typically, commercial producers sell weaned calves by the pound and therefore select seed stock genetics based on birth weight (high birth weight is correlated with decreased calving difficulties and increased number of live calves) and based on weaning weight (Van Eenennaam and Drake, 2012; Vestal *et al.*, 2013). Producers who retain ownership of their calves may select breeding stock based on different traits.

However, to maximize on pasture capacity and pregnancy rates, and to decrease the need for labour and fencing most commercial producers expose their entire bull battery to the cow herd in multisire pastures (Van Eenennaam and Drake, 2012). Therefore, commercial producers cannot usually identify the sire of each calf or tie progeny performance to their bull battery to make effective subsequent breeding decisions.

1.2.1.3 The feedlot sector

Feeder calves are purchased by feedlots either directly from the commercial producer or through auction marts. The feedlot sector of the industry feeds, or finishes, cattle for an average of 150 days until they are ready for slaughter (Schroeder, 2003). Feedlots find efficiencies, and therefore profit margin, in sourcing volume so that they are operating close to maximum capacities, and in sourcing healthy and consistent cattle that grow and finish at the same rates. Within the Canadian beef industry feedlots are paid per pound of carcass weight, with premiums for breed and grade should the cattle be going into branded beef programs with specific attribute requirements, and with discounts should the lean meat yield from the cattle be low. Canadian feedlots typically sell their cattle directly to packing, or processing, plants.

1.2.1.4 Packers and processors

According to Agriculture Agri-Food Canada (AAFC) there are 723 registered packing plants in Canada (AAFC, 2013). However, the majority of Canadian beef cattle are slaughtered and dressed at packing plants owned by either Cargill or JBS Foods. These companies are key players in the Canadian beef industry and Table 3 shows the daily killing capacity of their processing plants in Canada.

Table 3: Owner, location, and daily processing capacity (number of cattle) of the three largest and two midsized packing plants in Canada (CanFax, 2013).

Company	Plant Location	Daily Capacity
Cargill Foods	High River, AB	4,500
Cargill Foods	Guelph, ON	1,500
JBS Foods Canada	Brooks, AB	4000
Canadian Premium Meats	Lacombe, AB	400
Ryding Regency Meat Packing	Toronto, ON	200

Cargill and JBS Foods both process cattle for specific branded beef programs in addition to processing large quantities of commodity beef. For comparison's sake Table 3 also shows the daily capacity of two midsized packing plants including that of Canadian Premium Meats (CPM), a partner in this project. Smaller processing plants within the industry, including CPM typically accommodate custom slaughter and dressing for smaller customers and branded beef programs as opposed to processing large volumes of commodity beef. Packing plants also find the majority of their profits in efficiencies and volume.

Canadian processing plants pack cut beef as either fresh or frozen product. Further processing into products such as sausage, beef bacon and deli meats is typically done at secondary processors such as Vantage Foods, Calgary, AB and Vanderpol Enterprises, Abbotsford, BC. This processing adds value to beef product and provides beef consumers with greater choices on the type of beef product available for consumption (Schroeder, 2003).

1.2.1.5 Retail and food services sector

Downstream in the beef production chain are the beef retail sector, the food service industry, and ultimately, the consumer. Canada Beef Inc, a national organization responsible for the marketing and promotion of Canadian beef worldwide, coordinates guidelines and education programs for both the retail and food services sector, including accurate labelling guidelines and the safe food handling protocols (CBI, 2013). The objective for this agency is to promote increased linkage between the Canadian beef production chain and the retail and food services sector. In addition, the Alberta Livestock and Meat Agency (ALMA) conducts a biennial survey to identify and monitor Canadian consumer trends and industry opportunities (ALMA, 2012). Some of the consumer priorities and industry opportunities identified in the most recent ALMA survey of Canadian consumers are discussed in Section 2.1.3.

1.2.2 Fragmentation in the beef value chain

The sector based divide within the Canadian beef industry, predominantly the different pay out attributes for each sector, poses several limitations for the industry as a whole (Schroeder, 2003). These include:

1. Genetic selection limited to production traits such as calving rate and growth

2. Limited accuracy for the genetic selection tools available to producers
3. Minimal focus on increasing efficiencies throughout the chain and optimizing value across it
4. Limited information exchange between sectors

This project aims to deliver solutions to these four barriers, explored in greater detailed below, that the Canadian beef industry faces due, in part, to its lack of vertical integration.

1. Genetic selection limited to output traits:

Historically, genetic selection in the beef industry has been based on visual appraisal of individual breeding stock. More recently, Canadian beef producers have included the use of EPDs in their breeding programs (Rolf *et al.*, 2012). Since their inception in 1974, EPDs have enabled beef cattle breeders to make genetic progress in several economically important traits (Garrick, 2011). However, most EPDs published by Breed Associations focus on output traits, particularly growth to marketing points in the production cycle (Garrick, 2011; Rolf *et al.*, 2012). Because income gained by seed stock breeders and commercial producers is based on calf weight, at either yearling or weaning respectively, genetic selection in the past has been focused primarily on growth. Highly correlated with animal weight, carcass weight and lean meat yield are two traits that also benefit the rest of the Canadian beef industry. Garrick (2011) identifies that output traits are only one half of the equation necessary for profit. The Canadian beef industry may also realize significant value in pursuing efficiency traits such as feed efficiency, male fertility, and immune response (Miller, 2010; Wall, Bell and Simm, 2008). Predictions of genetic merit for a more holistic array of traits that impact all the sectors of the industry would elevate the Canadian beef industry's competitiveness (Schroeder, 2003).

2. Limited accuracy for selection tools:

In addition to describing efficiency traits, more accurate EPDs would also benefit the industry (Lobo *et al.*, 2011). EPDs are accompanied by accuracies that reflect the quality and quantity of information with which the EPD was calculated. EPD accuracies are published in terms of percentage with 1 percent being the least accurate and 100 percent being the most accurate. For example, EPDs based solely on pedigree information are generally limited to less than 10 percent accuracy. As individual performance information for an animal becomes available and it is incorporated into the calculation of its EPDs the accuracy of the EPDs increase. Ultimately, progeny performance information is the best source of accuracy in the calculation of EPDs (Bullock, 2009). Sires that are used extensively in the industry and have several hundred progeny in different herds and environments have EPDs with accuracies reaching 90 percent. Table 4 is the Possible Change Table for Canadian Angus EPDs generated in 2013.

Table 4: The Possible Change Table for Canadian Angus EPDs indicates how much an EPD can change (plus or minus the EPD) based on its accuracy (CAA, 2013).

EPD	BW (lb)	WW (lb)	YW (lb)	Milk (lb)	CED (%)	CEM (%)	Marbling (grade)	REA (inch²)	Fat (inch)
Accuracy	Possible change + or – EPD dependant on accuracy								
90%	0.26	1.2	1.7	1	0.8	1	0.03	0.03	0.004
80%	0.53	2.3	3.4	1.9	1.6	2	0.06	0.06	0.009
70%	0.79	3.5	5.1	2.9	2.4	2.9	0.09	0.1	0.0013
60%	1.05	4.6	6.8	3.9	3.2	3.9	0.12	0.13	0.017
50%	1.31	5.8	8.5	4.9	3.9	4.9	0.15	0.16	0.022
40%	1.58	7	10.2	5.8	4.7	5.8	0.18	0.19	0.026
30%	1.84	8.1	11.9	6.8	5.4	6.8	0.21	0.23	0.03
20%	2.1	9.3	13.6	7.8	6.2	7.8	0.24	0.26	0.035
10%	2.36	10.4	15.3	8.7	7.2	8.8	0.26	0.29	0.039

The Possible Change Table indicates how much an EPD might change as more information becomes available and its accuracy improves. For example, a yearling weight EPD with an accuracy of 10 percent might change up to plus or minus 15.3 pounds as more information becomes available. Whereas, a yearling weight EPD of 90 percent accuracy is typically within 1.7 pounds of the animals true genetic merit for the trait.

Large volumes of performance data are included in genetic evaluations to calculate EPDs with the highest degree of accuracy possible (Bullock, 2009). Breed Associations use performance information measured on purebred calves that are registered and raised for breeding purposes. However, relative to the feeder calf population this is a small number of calves. In addition, these calves are not typically slaughtered and measured for carcass quality; they are raised for use as the next generation of breeding stock. The impact of including feeder calf performance into genetic evaluations would be significant: for moderately inheritable traits, such as growth, the inclusion of performance information from 20 progeny can result in an increase in EPD accuracy of 30 to 40 percent (Northcutt, 2010). To extend the example above, a 30 percent increase in accuracy for a Yearling Weight EPD based solely on pedigree information with 10 percent accuracy would reduce the possible change range from plus or minus 15.3 pounds to a possible change range of plus or minus 10.2 pounds allowing prospective buyers for the particular breeding animal to make a selection decision with more confidence (Vestal *et al.*, 2013). The challenge in including feeder calf performance information into the calculation of EPDs is that commercial producers are usually unable to distinguish one bull's calves from another. This, and the disconnect between the seed stock sector and commercial producers are both lost opportunities to include significant amounts of progeny performance data into the genetic evaluations run by Breed Associations. The inclusion of feeder calf performance data would result in more accurate EPDs, and thereby, faster genetic gain for economically relevant traits (Van Eenennaam and Drake, 2012).

3. Minimal focus on increasing efficiencies throughout the chain and optimizing value across it:

Fragmentation within the Canadian beef industry has severely limited genetic selection for animals that are holistically profitable for all sectors of the industry (Garrick, 2011). The author states that beef producers should also select breeding candidates that improve consumer satisfaction by influencing:

i. Immediate eating quality – influenced by carcass quality traits such as marbling grade, back fat and rib eye area. This DNA tracking system will link feeder calf carcass quality information back to seed stock genetics identifying breeding animals with superior genetic merit for better eating experiences.

ii. Purchase cost – production efficiencies, for example genetic selection for improvement in male fertility by identifying less prolific bulls are an opportunity to address the cost of production and therefore the cost of Canadian beef. Van Eenennaam (2010) simulated the application of DNA technology on commercial multisire operations for five years in North Carolina. The author found a difference of $51,008 in profits due to differences in sire prolificacy. Other opportunities to address production costs include improving genetic merit for residual feed intake and animal health (see Chapter 4). Purchase cost for Canadian beef can also be driven down or maintained by increasing production through more accurate identification and selection for superior genetic merit of growth traits, carcass weight, and lean meat yield (Garrick, 2011). Another opportunity to increase efficiencies would be to record and apply information to improve feed efficiency. Feed is estimated to comprise over 60 percent of the production cost in calf feeding systems and over 70 percent in finishing systems and may be an opportunity to increases efficiencies in beef production significantly (Rolf *et al.*, 2012).

iii. Environmental impact – Genetic selection for feed efficiency would also, indirectly, result in reduction of enteric methane emissions in beef cattle (Basarab *et al.*, 2013). Modern beef production practices have helped decrease the beef industry's impact on the environment, however, genetic selection for cattle that consume less feed per lb of growth, produce less waste and greenhouse gases would be beneficial (Capper and Hayes, 2012).

iv. Animal health and welfare – Despite the significant loss in production and profits, the impact of Bovine Respiratory Disease (BRD) alone cost the industry 4.28 billion dollars in loss in 2010, Canadian beef producers do not apply any selection pressure for improved genetic potential for disease resistance (Stegnar, 2013). In addition, as per Verbeke and Viaene (2000), the Canadian beef industry must communicate its commitment to animal welfare to consumers in order to maintain a competitive advantage. This system would label verify for the consumer animal welfare attributes for a Canadian beef product branded as such.

Garrick (2011) suggests that the design of a beef cattle improvement program should consider traits that influence production efficiency such as individual animal measures of inputs and outputs, traits that influence the quality of the eating experience, traits that influence animal health, and traits that influence the human healthfulness of the consumed beef.

4. Limited information exchange between sectors:

Currently, each sector of the beef industry invests significant resources in recording certain performance traits (Garrick, 2011). The seed stock sector records pedigree and performance information with Breed Associations, commercial producers typically record birth weights and weaning weights, the feedlot sector maintain extensive records on health and average daily gain, and packing plants record carcass quality information.

Relaying performance measures upstream in the production chain where they can be applied to make subsequent breeding decisions would maximize the value of this industry investment (Garrick, 2011). In recognition of this the Canadian beef industry, led by the Canadian Cattlemen's Association (CCA), developed an information exchange pipeline called the Beef Information Exchange System (BIXS). BIXS is essentially a database into which animal information can be recorded. The premise of the system is that producers will create animal records and sectors downstream of producers will populate the database with additional performance information for each animal (CCA, 2013). Access to animal information is only provided to individuals who in turn provide information. Theoretically, the producer who created the animal record will access feedlot growth and health information and carcass quality information uploaded by the packing plant and apply the information towards future selection decisions.

BIXS is based on every animal having a unique identification number. This identification number is assigned by virtue of a Radio Frequency Identification (RFID) tag that is issued and monitored by the Canadian Cattle Identification Agency (CCIA). This mandatory national animal identification system, which will be described in greater detail in Section 2.6.4, enables the Canadian beef industry to track cattle through the production chain and can be leveraged to expand both local and international markets. The Canadian Angus Association (CAA) distributes a subset of CCIA issued RFID tags to commercial producers who use registered Angus bulls in their breeding programs. The CAA RFID tags have distinct green backs stamped with a large A on them (see Figure 3). These tags guarantee feeder calf buyers a minimum of 50 percent Angus genetics as only progeny of at least one registered Canadian Angus seed stock animal qualify for these tags.

Figure 3: CAA RFID Tag that fulfills the National animal identification and animal movement tracking requirements and also provides potential buyers a visual guarantee of a minimum of 50 percent Angus genetics (CAA, 2013).

Animal performance information is accessed from BIXS based on the animal's RFID number. As discussed prior, downstream performance information on feeder calves is of limited value unless commercial producers can identify the correct parentage of their feeder calves. An additional limitation to data accessed from databases such as BIXS is that the information is not organized in a format that is easily applied towards genetic improvement. The primary goal of this project is to create linkage between data and genetics, and present producers with readable and useable progeny performance information.

Schroeder (2003) reports that the Canadian beef industry does not effectively address consumer demands. These demands include consistent and high meat quality as well as breed distinction, guarantees of quality, food safety assurances, animal welfare and environmental stewardship assurances (ALMA, 2012; Van Wezemael *et al.*, 2013). This project aims to access feeder calf identification and performance data from producers, feedlots and packing plants directly, or through databases such as BIXS, and apply high throughput DNA technology to create links between sires and calves for genetic improvement, and between calves and beef for label verification. This system may facilitate increased vertical integration within the Canadian beef industry and help address the four challenges identified above.

Despite industry efforts such as the Straw Man Initiative funded by the Alberta Livestock and Meat Agency (ALMA) and the Beef Value Chain Roundtable (BVCR) meetings hosted by Agriculture and Agri-Food Canada (AAFC) to engage all sectors of the industry in regulation and strategic planning, many beef stakeholders report that the sector is operating without a strategy, minimal collaboration, no vision, no sense of common objectives and fragmented leadership (CAPI, 2012).

This project addresses the above four linkage opportunities by linking feeder calves and their performance at the feedlot and packing plant to their appropriate sires for selection purposes. This project also delivers increased sustainability to the industry by addressing consumer demands for label verification which is discussed at length in Section 2.5.

Chapter 2: Literature Review

2.1 Challenges faced by the Canadian beef industry today

The world population and Canada's national population are both growing at a rate of 1.4 percent annually (Stats Canada, 2013). Considering that historical changes in the demand for livestock products have been driven by human population growth, income growth and urbanization this explosive rate of population growth should increase future demand for meat products (Thornton, 2010). Beef is a particularly good source of protein and important micronutrients such as niacin, vitamin B6, vitamin B12, phosphorus, zinc and iron (Williams, 2007). However, demand for beef products in the future could be heavily moderated by environmental, socio-economic factors and socio-cultural values (Thornton, 2010). Today, the Canadian beef industry faces a considerable challenge in producing sufficient animal protein to fulfill the needs of the growing national population whilst battling competition for natural resources, adapting to global climate change, and facing intense competition from other protein sources (Stats Canada, 2013). These three challenges are discussed below.

2.1.1 Competition for natural resources

Thornton (2010) and Godfray *et al.* (2010) postulate that growing competition for land, water, and energy will affect the beef industry's ability to produce food. Accordingly, the Canadian beef industry should address any opportunities to produce more food using fewer inputs as competition for land, water, and energy intensifies (Capper and Hayes, 2012). In agriculture useable land is defined as all land that is not desert, tundra, rock or boreal. Globally, about half the useable land is already used for pastoral or intensive agriculture (Tilman *et al.*, 2002). In Canada, population growth and urban development have contributed significantly to competition for land. In 2011 a total of 160,155,748 acres were farmed in Canada, this is down 4.1 percent since 2006 (Stats Canada, 2012).

Competition for uncontaminated water is also a growing concern for the Canadian beef industry. Irrigated agriculture is the main source of water withdrawals, accounting for approximately 70 percent of the world's freshwater withdrawals (Rosegrant, Ringler, and Zhu, 2009). Forty per cent of crop production comes from irrigated agricultural land and over pumping groundwater is a serious concern (Tilman *et al.*, 2002). Moreover, the author reports that urban water use, restoration of streams for recreational, freshwater fisheries, and protection of natural ecosystems are all providing competition for water resources previously dedicated to agriculture. Finally, irrigation return-flows typically carry more salt, nutrients, minerals and pesticides into surface and ground waters than in source water, impacting downstream agricultural, natural systems and drinking water (Tilman *et al.*, 2002). In Canada, Alberta especially, the oil and gas industry adds increased competition for clean water.

2.1.2 Challenges of global climate change

In addition to fierce competition for resources like land and water, changes in global climate could have profound implications for world agriculture production (Baker *et al.*, 1993). Use of fossil fuels since the industrial revolution has elevated atmospheric CO_2 levels and until alternative energy sources are adopted extensively, greenhouse gases such as CO_2 will continue to result in significant change in global climate. Since the industrial revolution, the global average temperature has risen between 2.8 and 6.4 degrees Celsius (Mader *et al.*, 2009). An example to illustrate the seriousness of this situation is the European heat wave of 2003 which killed some 30,000 to 50,000 people and led to up 36 percent decrease in the agricultural yields for the area (Fedoroff *et al.*, 2010). In addition to production loss due to heat stress, possible impacts of climate change on agricultural production include extreme weather events that can affect fodder quality and quantity, host-pathogen interactions, and disease epidemics (Thornton, 2010). For instance, as sea levels rise due to climate change low-lying crop-land will be submerged, and as glaciers melt causing river systems to experience shorter and more intense seasonal flows the instances of flooding will increase (Fedoroff *et al.*, 2010). Extreme precipitation and flooding within Alberta in 2013 had significant effects on Canada's agricultural sector and has resulted in enormous costs to the Canadian economy (AAFC, 2013).

2.1.3 Competition from other proteins

Although the net need for food is growing with the global population, the Canadian beef industry needs to compete with other food sources. The Canadian Consumer Retail Meat Study 2012 conducted by ALMA indicates that dramatic changes in Canadian consumer protein choices have occurred since 2010. Canadians indicated that 44 percent are eating less beef, 32 percent are eating less pork, while 45 percent reported that they are eating more chicken, and 66 percent said they are eating more fish now than in 2010. Moreover, these respondents expect to be eating even less beef and pork, and more chicken and fish, in the next five years (ALMA, 2012). Brester (2012) and Zhang and Goddard (2010) also reported that while per capita meat consumption has grown there has been a decline in demand for beef since early 1970 when only 13 percent of Canadian meat consumption was poultry. Since then, consumption of poultry increased by 136 percent, taking substantial market share from beef products (Zhang and Goddard, 2010).

According to the Canadian Agri-Food Policy Institute's (CAPI) report to ALMA the loss in market share that the beef industry has experienced in the past two decades can be attributed to several factors including:

1. Price
2. Concerns about food safety
3. Consumer concerns in regards to the nutritional value of beef
4. Environmental stewardship
5. Animal welfare
6. Lack of response to consumer demand

Each of these factors is discussed below.

1. Price:

Analysts propose several theories as to why the beef industry has lost its competitive advantage to the poultry, pork and fish industry. Price is a significant limiting factor (Deblitz and Dhuyvetter, 2013). According to Piggott and Marsh (2004), price is the primary factor upon which consumer decisions for protein choice are made. For comparison, in 1950, beef was selling 20 percent more than the price of chicken however by the early 90's, beef was selling for 70 percent more than the price of chicken (Cunha, 1991). According to Stats Canada (2012), depending on the cut and quality grade of beef one kilogram of beef can still cost up to 70 percent more than one kilogram of chicken. Table 5 lists the average price of different cuts of beef, pork and poultry in Canada from 2009 to 2013 for comparison.

Table 5: The average price of several different cuts of beef, pork and poultry in 2009, 2010, 2011, 2012, and 2013, illustrating how much more expensive beef can be, depending on the cut, than other protein sources (Stats Canada, 2012).

	Aug-09	Aug-10	Aug-11	Aug-12	Aug-13
	$ per 1 kg				
Sirloin steak	16.3	14.9	16.3	17.8	17.4
Prime rib roast	22.5	20.7	22.1	23.7	23.8
Blade roast	10.1	10.2	10.8	11.3	12.1
Stewing beef	10.2	9.9	10.5	11.4	11.5
Ground beef	7.1	7.7	8.3	9.1	9.4
Pork chops	9.6	9.6	10.3	10.1	10.9
Chicken	6.4	6.5	6.6	6.9	7.3

Canadian consumers reported to ALMA that while they feel more financially stable than they were in 2010, they continue to search for value in their meat purchases (ALMA, 2012).

2. Concerns about food safety:

Changes in consumption distribution across different kinds of protein and attitudes towards meat are influenced significantly by food safety related scares (Grunert, 2006). Unfortunately for the Canadian beef industry, well publicized food safety events have occurred frequently in the past 10 years. The discovery of BSE in an animal in Alberta in May of 2003 and the impact of the resulting international trade ban was a devastating blow for the Canadian beef industry (Lewis, Krewski, and Tyshenko, 2010). In 2003, Canadian farm cash receipts from cattle and calves were estimated at $5.2 billion, a sharp drop of $2.5 billion (33%) from 2002 (Hobbs *et al.*, 2005).

Just as markets were recovering, there was a widespread outbreak of listeriosis in 2008. This was shown to be due to cold cut meats from a Maple Leaf Foods plant in Toronto, ON. There were 57 total confirmed cases and 22 people died from having consumed the contaminated product (Weatherill, 2009). Although the contamination was not limited to beef products, according to Marsh, Schroeder, and Mintert (2004), food safety outbreaks pertaining to any type of meat leads to consumers making non-meat purchasing decisions.

To maintain food safety at the forefront of the Canadian beef consumers' mind, what would soon become the largest recall of beef and beef products in Canadian history began on September 4, 2012 at the Brooks, AB beef processing plant owned and operated by XL Foods Inc (now owned by JBS, see Table 3). By October 15, beef processed at the plant and contaminated with Escherichia coli (E. coli) O157:H7 had made 18 consumers sick. Some 1,800 products were removed from the market in Canada and the United States as the result of a voluntary recall by XL Foods Inc. (Lewis, Corriveau, and Usborne, 2013). During the food safety investigation associated with the outbreak, it was determined that the contamination was likely associated with mechanically tenderized beef (Catford *et al.*, 2013).

These are just three of the food safety scares that have occurred in the past decade. They are momentous enough to make concern for food safety prevalent in any Canadian beef consumers mind. Schroeder and Mark (2000) found that beef recalls by the Food Safety Inspection Service (FSIS) caused declines in beef demand, especially in years when a relatively large number of recalls occurred. The Canadian beef industry, through the CCA, is developing an organized communication and industry response procedure in preparation for another food safety crisis (CBI, 2013). At the 38th Beef Value Chain Roundtable meeting in Calgary on October 30th, 2013 CCA reported the need for an integrated industry wide effort to communicate Canadian beef as a safe, high quality product (ALMA, 2012). Label verification systems like the one designed and demonstrated within this project may help increase consumer confidence on the safety of Canadian beef.

3. Consumer concerns in regards to the nutritional value of beef:

In addition to the (perhaps perceived) risk of consuming contaminated beef product, the Canadian beef industry must also contend with the fact that consumption of red meat has been associated with increased risk of disease for some time now. Substantial evidence from epidemiological studies shows that consumption of meat, particularly red meat, is associated with increased risks of diabetes (Pan *et al.*, 2011), cardiovascular disease (Micha, Wallace and Mozaffarian, 2010), and certain cancers (Zheng and Lee, 2009). Studies postulate that long-time beef consumption increases the risk for cancer of the colon by as much as 20–30 percent, as well as being linked to an increased mortality rate for colorectal cancer (WCRF, 2007; Huxley *et al.*, 2009). Other studies have implicated beef consumption as a risk factor for other cancers such as premenopausal and postmenopausal breast cancer (Ferrucci *et al.*, 2009).

Health and nutrition concerns have had a long-term gradual downward influence on beef demand. However, a review of some of the studies associating beef consumption with health risks by McAfee *et al.* (2010) reports methodological limitations within the studies. In addition, there are numerous studies showing the nutritional benefits of beef consumption, as long as consumption is limited to recommended quantities. Some of these benefits include intake of unsaturated fatty acids, conjugated linoleic acid, proteins, vitamins and minerals vital to physical, psychological and socio-economical health (McAfee *et al.*, 2010). This underscores the importance of industry efforts to provide balanced health information to consumers via consumer, nutritionist, and health advisor education (Schroeder and Mark, 2000).

4. Environmental stewardship:

In addition to human health, the beef industry has also been implicated in our planet's current declining health status. Steinfield *et al.* (2006) report that the agricultural industry consumes fossil fuel, water, and topsoil at unsustainable rates. In addition, it contributes to numerous forms of environmental degradation, including air and water pollution, soil depletion, diminishing biodiversity, and fish die-offs (Steinfield *et al.*, 2006). Significantly, meat production contributes disproportionately to these problems, in part because feeding grain to livestock to produce meat (instead of feeding it directly to humans) involves a large energy loss, making animal agriculture more resource intensive than other forms of food production (Horrigan, Lawrence, and Walker, 2002). In addition, livestock systems are reported to be significant sources of greenhouse gas emissions, particularly methane (CH_4) and nitrous oxide (N_2O) (Steinfield *et al.*, 2006). Livestock account for up to 40 percent of the world CH_4 production, a proportion of which comes from enteric fermentation and another from anaerobic digestion in liquid manure. Sixty-four percent of global nitrous oxide emissions are due to agriculture, chiefly due to fertilizer use (Steinfield *et al.*, 2006).

Garnett (2009) reports that although an extensive review of studies indicates that livestock production is the most greenhouse gas intensive of all food production, different foods perform different nutritional roles in our diet and that this should be considered as well. Garnett (2009) urges researchers to consider the environmental cost of eliminating livestock agriculture and cultivating increased areas of land to grow enough plant based food to provide adequate nutrition to the global population. In addition, Herrero *et al.* (2011) report that livestock agriculture accounts for 8 to 51 percent of greenhouse emissions depending on the study and methodology. This variation instils scepticism in politicians creating regulations to protect the environment and in consumers. Authors Pitesky, Stackhouse, and Mitloehner, (2009) and Place and Mitloehner (2012) offer solutions to standardize estimates of environmental impact. Life cycle assessments are analysis tools that help estimate the carbon footprint of agricultural products based on standardized carbon dioxide equivalents per unit of product considering all stages of the production chain involved in the industry (Place and Mitloehner, 2012).

It has been shown that cattle that are more efficient in regards to converting feed to gain and in regards to gain per day fed use less resources and emit less greenhouse gases (Miller, 2010). There is much opportunity to communicate to Canadian consumers that Canadian agriculturalists, farmers and producers are strong stewards of the Canadian and global environment. For example, the Canadian livestock industry recognizes and celebrates beef producers who invest in environmental protection through The Environmental Stewardship Award (TESA) (CCA, 2013). Internationally, efforts to communicate the industry's commitment to the environment include CBI's recently deployed marketing campaign in South American and Asian markets. The campaign promotes Canada's pristine environment and Canadian beef producers' commitment to preserving their environment (CBI, 2013).

The DNA tracking system designed and demonstrated within this project should allow for more accurate identification of efficient genetics improving the rate of genetic gain for these traits and therefore contribute to reducing the environmental footprint of the Canadian beef industry. It will become important to communicate these attributes to both Canadian consumers and international markets in order to challenge the current perception of the industry having a significant negative impact on the environment.

5. Animal welfare:

Beef production today also faces the difficult task of effectively meeting emerging consumer concerns about animal welfare while remaining competitive in major target markets (Verbeke and Viaene, 2000). Schröder and McEachern (2004) studied ethical attitudes in relation to meat purchases among urban and rural consumers in Scotland. All the subjects surveyed perceived some ethical issues in relation to animal production systems, specifically to animal confinement, and beef product that offered animal welfare-friendly labelling was considered value-added. Interestingly, in their study, the authors found that typically individuals hold two sets of views on animal welfare. On one hand they may think as citizens influencing societal standards, and on the other, as consumers at the point of purchase. As citizens, they support the notion of animals being entitled to a good life; as meat consumers, they avoid the cognitive connection with the live animal (Schröder and McEachern, 2004).

Recently, Canadian beef producers, with the support of governmental agencies such as CBI and Alberta Beef Producers (ABP), have recognized the importance of 'telling their story' to the Canadian beef consumer in an effort to elevate consumer perception of Canadian beef production practices. Several initiatives, such as 'Raised Right' aim to correct consumer perceptions of how Canadian cattle are raised. The 'Raised Right' campaign is designed to give consumers a human image to connect with and reinforce the message that Alberta beef is raised responsibly and ethically by people who embody traditional family values. ABP states that the 'Raised Right' campaign is important to the entire industry because it is vital to tell consumers that Alberta beef is a healthy sustainable protein choice to make (ABP, 2008). On an international basis, CBI promotes the Canadian Beef Advantage campaign that communicates the humane and fair raising of Canadian cattle (CBI, 2013).

Several branded beef programs now label their product as raised humanely. For example, Sobeys, a major Canadian grocery retailer offers its customers a line of Certified Humane brand meat and poultry (Sobeys, 2013). The DNA tracking system from this project may offer an audit and label verification opportunity for beef products differentiated with such attributes. In the example above, Sobeys sources its humanely raised beef from a CAA member and Canadian seed stock breeder Aspen Ridge Farms CAA, 2013). The DNA tracking system from this project can be applied to sample a proportion of the product being retailed by Sobeys to verify that it did in fact originate from Aspen Ridge Farms. This verification may give Canadian beef consumer heightened confidence in purchasing this line of beef.

6. Lack of response to consumer demand:

Superior knowledge of customers' perceptions of value is recognised as a critical success factor in today's competitive marketplace. Despite this, the voice of the consumer is often poorly integrated within the value chain (McEachern and Schröder, 2004). Canadian beef consumers report that tenderness and flavour as the primary attributes that they look for in beef (Schroeder, 2003). Yet, there is very little work in the industry to address these traits. Marbling, which positively associated with tenderness and juiciness, is reported in both Canadian and U.S. beef audits to be at the same level today as it was in 1990 (ALMA, 2012; Mckenna *et al.*, 2002). Inclusion of feeder calf marbling scores measured at the packing plant into the selection of breeding stock might increase consumer satisfaction in Canadian beef significantly. Schroeder and Mark (2000) report that the top five ranked beef quality concerns are 1) low overall uniformity and consistency; 2) inadequate tenderness; 3) low overall palatability; 4) excessive external fat; and 5) high price for the value received. These are all attributes that can be selected for and improved upon using the DNA tracking system from this project.

Increased information flow between sectors of the Canadian beef industry and increased resources for branded beef programs through this project might also assist the Canadian beef industry in meeting consumer demands for more convenience product. Anderson and Shugan (1991) report that the beef industry has also been losing market share to poultry based on the attribute of convenience. The poultry industry reacted to consumer feedback about poultry being too dry and inconvenient to prepare as whole products by injecting the product with water, pre-marinated product, and by pre-processing it into easy to prepare meals and portions (Cunha, 1991). The Canadian beef industry has done very little in response to consumer feedback, in part because of the lack of vertical linkage within the industry (Schroeder, 2003).

Addressing identified consumer demands is only half the challenge facing the Canadian beef industry. The other half of the challenge is to communicate the industry's response to national and global markets. ABP and CBI's campaigns aim to elevate the industry's position in these markets (ABP, 2008; CBI, 2013). None-the-less consumer surveys identify that Canadian beef consumers are choosing alternative proteins because they are concerned about health, the environment, and social responsibility issues, i.e. ethical treatment of animals (CAPI, 2012). CAPI (2012) reports that consumption because consumers are more informed and aware of issues and their purchasing decisions are increasingly driven by degrees of trust in the product and the source of supply. Increased branded beef programs with label verification might assist in promoting Canadian beef to consumers (Schroeder, 2003).

2.2 Opportunity presented by population growth

The Food and Agriculture Organization (FAO) is projecting a 70 percent increase in the demand for meat, milk and eggs in order to feed the global population which is predicted to increase from the current 7 billion people to over 9.5 billion by the year 2050 (Capper and Hayes, 2012). The demographic that can afford to purchase meat in both developed and developing countries is also growing substantially, particularly in countries with growing middle class populations in which affluence is also on the rise (Lamb and Beshear 1998; CAPI, 2012). The global population is rapidly becoming more urbanized which leads to increased incomes and increased consumption of meat (Thornton, 2010). In 1975, approximately one-third of the world's people lived in cities; that figure is expected to rise over 60 percent by 2030 (Capper and Hayes, 2012). China offers a sobering case in point: meat consumption nearly doubled countrywide during the 1990s however, the increase was most pronounced among urban residents (Horrigan, Lawrence, and Walker, 2002). Heavy urbanization also leads to infrastructure such as cold chains that allow for the trade and transportation of perishable foods (Thornton, 2010). Increased populations, expanding middle class demographics, and increased urbanization are resulting in increased demands for animal-based food products (Ludu and Plastow, 2013). The Canadian beef industry is foregoing these opportunities and its competitive position is falling behind (CAPI, 2012). The changing demographics of the global population pose a significant opportunity for expanded markets that the Canadian beef industry might exploit (Pretty *et al.*, 2010).

2.3 Vertical integration

Currently in the Canadian beef industry, seed stock breeders and commercial producers that may invest in selection tools for carcass quality do not receive any additional return for doing so (Garrick, 2011). Therefore, at the genetics level of the production chain, there is little incentive for any improvement in beef quality. In order to provide financial cues to these two sectors of the beef industry, there may need to be a reduction in the number of cash market trades. Producers may need to increase direct marketing or longer-term relationships that profit share based on carcass quality (Lawrence, Schroeder, and Hayenga, 2001).

Increasingly, the Canadian beef industry is seeing beef producers establish stronger relationships with sectors downstream in the chain, or retain ownership and market their own cattle (Hobbs and Young, 2000). CanFax (2013) reports that in the past five years the number of feeder calves in Alberta, Saskatchewan, and Manitoba sold through auction marts has decreased from 2.05 million head / year to 1.46 million head / year. This decrease can be attributed to a decrease in the size of the Canadian cow herd, but also to an increase in direct sales and increased vertical integration. This integration, or retained ownership of feeder calves, changes the pay structure to the producer to include premiums and discounts based on carcass quality. Premiums for increased marbling grade and discounts for increased back fat or low lean meat yield may incentivize genetic and environmental improvement for these consumer demanded attributes. Whether termed communication, coordination, alignment, relationships or alliances, the end result is to create an industry that sees the benefits of vertical integration without complete ownership (Peters, 2001).

Schroeder (2003) states that one segment of the vertical chain cannot profit at the expense of another segment or trust will rapidly be lost. For example, cow-calf producers rely on seed stock suppliers to provide accurate and reliable information regarding animal pedigree and performance information. Similar information, in addition to preconditioning and vaccination programs, is relevant from the cow-calf producer to the feedlot. Likewise, the packer benefits from knowing cattle quality and yield expectations from the feedlot much like the retailer benefits from anticipating quality and yield of meat cuts from the packer. Each vertical stage of the production and marketing chain benefits from having knowledge of what they are purchasing from their upstream suppliers. Currently, most feedlots in Canada vaccinate all feeder calves on arrival despite any health treatment records that they receive. This is a gross inefficiency and supports the consumer perception of pharmaceutical misuse. However, despite having a mandatory national cattle identification system and information exchange systems such as BIXS in place, the fragmentation within the Canadian beef industry does not support the transfer of reliable information about previous health treatments, nor does it foster any trust between sectors of the industry.

According to Peters (2001) there are two distinct benefits result from vertical integration. First, production efficiency is increased as a result of better communication among the production segments, less cost duplication and more efficient use of resources to optimize production. Second, control throughout production greatly enhances marketing power to the consumer by ultimately guaranteeing source, specific production and management practices, food safety and eating quality. In addition to information flowing downstream, information flow upstream in the production chain from consumer to retailer to packer to feedlot to commercial producer and seed stock breeder would facilitate genetic selection and management in response to consumer feedback. Therefore, a third benefit of this DNA tracking system, as a result of vertical integration, would be a more consistent higher quality Canadian beef product.

Recently, there has been recognition of the value of increased integration within the Canadian beef industry. The Canadian Agri-Food Policy Institute (CAPI) reported to the ALMA that Canada's beef sector needs a robust, long-term strategy – and a sustained commitment to execute the strategy – if it wishes to secure its place as a competitive force in domestic and global markets (CAPI, 2012). In response ALMA created the Straw Man Initiative that brought together three key industry figures within a committee to draft a Straw Man Model strategy for a successful Canadian beef industry. Each sector of the beef industry has been invited to provide feedback and commitment of support to the strategy (ALMA, 2012).

The poultry and pork industries have been successful by transforming themselves into consumer-driven industries, a move that has both driven down costs and enhanced the consumer appeal of their products (Lamb and Beshear, 1998). A key in accomplishing the transformation for these two competing protein industries was achieving a high degree of coordination between different links in the production chain - vertical linkage (Lawrence, Schroeder, and Hayenga, 2001). This DNA tracking system encourages linkage between seed stock breeders, commercial producers, feedlots and packing plants that participate in branded beef programs or in retained ownership agreements. As these participants see increased value in data sharing the segregation of sectors that currently exists in the industry might erode. Schroeder (2003) suggests that each segment of the vertical market chain from seed stock and cow-calf producers through feedlots, packers, and processors must work together toward a common goal for the target market. Currently, each sector within the industry has its own goals based on the basis of payment. In order to achieve successful integration, all sectors would have to select and manage cattle based on efficiencies and profit at each sector and the entire industry's endpoint – consumer satisfaction. Garrick (2011) describes this as balanced or holistic selection for animals that benefit the entire industry by performing well in each sector and on the plate.

2.4 Genetic improvement

Until the eighteenth century genetic gain in livestock occurred through natural selection and adaptation to the environment (Bullock, 2009). Robert Bakewell, now renowned as the pioneer of livestock improvement introduced to the world of agriculture the concept of selective breeding and influenced significant improvements in Leicester sheep and Longhorn cattle (Willham, 1986). Bakewell formed the first Breed Association or Society with the aim of preserving the genetic purity of the Dishley sheep. The first National Cattle Evaluation (NCE) to assess the genetic merit of cattle was performed in 1974 (Willham, 1986). Since then, models have evolved from single-trait sire models to the multi-trait animal models used today (Rolf *et al.*, 2010). Today, pedigree and performance information is used in genetic evaluations to generate predictions of genetic merit (such as EPDs) for breeding stock in most livestock industries.

EPDs predict, to a specified level of accuracy, the average expected performance of a breeding animal either in comparison to the average progeny of another animal or the breed average. Figure 4 shows the expected difference in average progeny performance for weaning weights from two bulls that differ by 25 lb for Weaning Weight EPD (Bullock, 2009). Similar to the example illustrated in Section 1.2.1 the progeny from the bull with the higher Weaning Weight EPD are expected to be heavier, on average, than the progeny from the bull with the lighter Weaning Weight EPD. The value of the EPD does not indicate the actual phenotypic weight of the bulls' calves which is a product of their genetic merit and their environment. EPDs merely describe the difference to be expected in the average of the progeny performance given the same opportunity to develop the trait in question (Bullock, 2009)

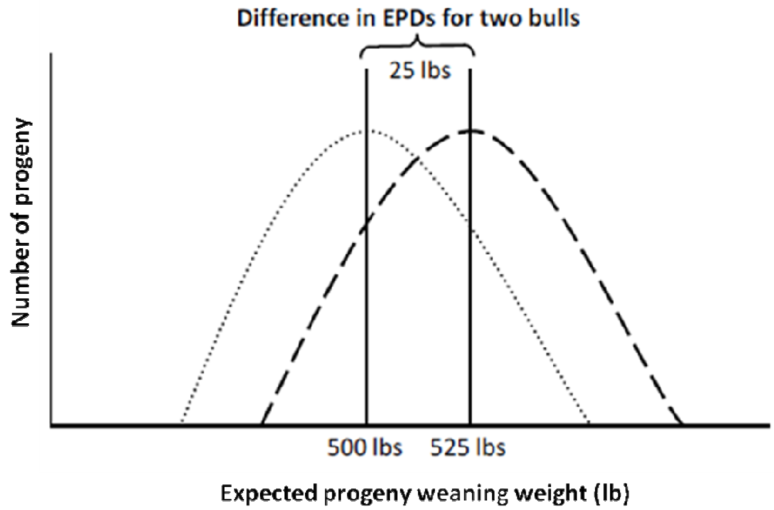

Figure 4: The expected difference, 25 lb on average, at weaning for the progeny of two bulls with Weaning Weight EPDs differing by 25 lb (Bullock, 2009).

As published genetic trends demonstrate, genetic improvement in beef using EPDs as selection tools has been successful, (Miller, 2010; Lobo *et al.*, 2011). However, for beef cattle, these gains in genetic progress are limited to traits that are included in Breed Association evaluation programs (see Table 2) and also by the accuracy of the EPDs reported (Garrick, 2011; Lobo *et al.*, 2011).

In comparison, livestock production in other industries has increased substantially since the 1960s. Havenstein, Ferket, and Qureshi (2003) compared broiler chickens from 1960 to broilers from 2001 and found that on average broilers have gone from weighing 168g at 21 days to weighing 743g at the same age. The poultry industry has selected for birds that grow faster and require less feed to do so, thereby, also selecting for more efficient birds that have a decreased impact on the environment. Genetics, nutrition, and other management changes over the last 44 years have resulted in broilers that require approximately one-third the time (32 vs. 101 days) and a threefold decrease in the amount of feed consumed to produce a 1,815g broiler (Havenstein, Ferket, and Qureshi 2003). Similarly, the turkey industry has achieved genetic gain, improvements in management, housing, nutrition, and disease prevention through increased vertical integration. The resulting improvement in product has contributed to the increase in per capita consumption of turkey meat, which has risen from about 1kg in 1950 to about 7.9kg in the U.S. in 2004 (Havenstein *et al.*, 2007). Since 1960 milk production in North America has increased by 300 percent, the pig industry has decreased finishing time by almost 50 percent; egg production per hen is up 90 percent (Havestein 2003; Thornton, 2010). Fix *et al.* (2010) report that the U.S. swine industry has realized a 45 percent improvement in lean efficiency in the past 25 years. The UK government reported (see Figure 5) that in the past 22 years the UK dairy, sheep and pig industries have reduced their impact on the environment by reducing greenhouse gas emissions significantly (Gov.UK, 2013).

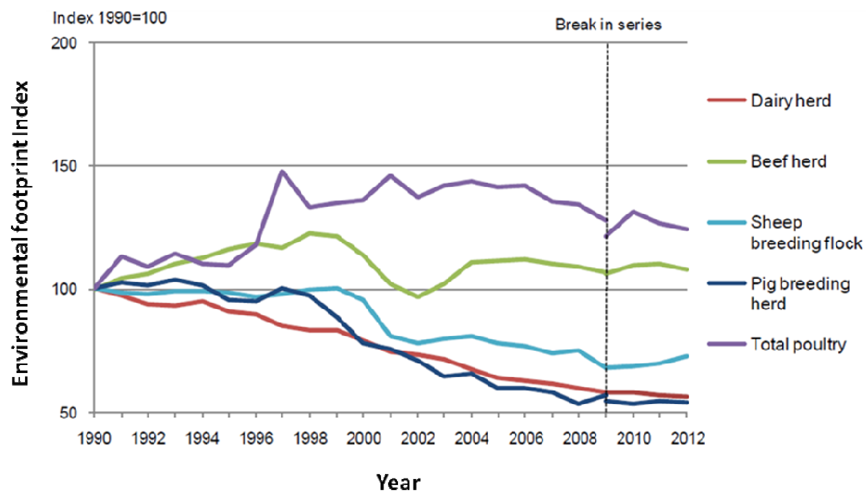

Figure 5: Greenhouse gas emissions for UK livestock industries, showing a reduction in environmental foot print for the dairy, sheep and pig industry between 1990 and 2012 (Gov.UK, 2013).

Improved genetic potential for growth and finishing efficiencies may drive down both the cost of beef production and the industry's impact on the environment. Improving the genetic potential for carcass quality might also elevate the competitive position of the industry. However, the Canadian beef industry is structured such that carcass harvest records for progeny of seed stock are not easily accessed. Subsequently, since the 1990's ultrasound scanning information has been used as an indicator for carcass traits (Miller, 2010). However, as with other indicator traits, ultrasound scan data has a lower correlation to the trait of interest than progeny carcass merit (Northcutt, 2010). In order to influence the rate of genetic gain progeny performance should be included in the calculation of EPDs.

De Roos *et al.* (2011) state that the value of increasing the accuracy of selection tools and use younger bulls, and decrease the generation interval, can double the rate of genetic gain. Rates of genetic change have increased in recent decades as selection tools and breeding techniques become more sophisticated, including more efficient statistical methods for estimating the genetic merit of animals, the wider use of technologies such as artificial insemination, and more focused selection on objectives (Thornton, 2010). A system that attributes progeny performance and carcass quality data back to the sire for genetic selection based on more accurate information and facilitates a greater degree of vertical linkage in the supply chain would be of great benefit to the Canadian beef industry.

2.5 Branded beef products

As discussed in Section 1.2.3, the Canadian beef industry has access to several agencies that help brand and promote Canadian beef in order to elevate consumer appreciation of the product. Product branding is essentially the development of labelling, via name, phrase, symbol or design, which identifies the product and its attributes. According to Schroeder (2003) there are three reasons to develop a brand:

1. Differentiating product
2. Conveying value
3. Building loyalty

These three reasons for brand development are discussed below.

1. Branding allows one to differentiate product from competitors:

This transforms commodity product to a product that might be positioned for differentiated pricing and targeted consumer markets (Schroeder, 2003). Branding can help differentiate Canadian beef products and identify attributes such as breed composition, increased food safety assurances, animal welfare and environmental responsibility assurances, animal management and health treatment assurances (e.g. no added growth hormone – no antibiotics), and carcass quality assurances (e.g. marbling grade and tenderness guarantees).

In 1978, the American Angus Association developed the Certified Angus Beef® (CAB) brand. Today, CAB has achieved 44.4 percent of the U.S. beef market share. Of the 71 officially recognized U.S. branded beef products, 53 have the word Angus in them (Siebert and Jones, 2013). Differentiation using breed information can be successful; in North America especially, the word Angus has become synonymous with quality (Nelson *et al.*, 2004). The authors evaluated CAB branded steaks in comparison with USDA Choice (commodity) and USDA Select (high quality, well marbled) and found CAB product to have improved tenderness and palatability (Nelson *et al.*, 2004). Feldkamp, Schroeder, and Lusk (2005) found that consumers were willing to pay an economically important premium exceeding $2.00 per steak for CAB product relative to generic steak. In another study, Parcell and Schroeder (2007) found that when supermarket branding was compared to Angus beef branding, Angus branded medium-quality and high-quality steak cuts commanded premiums of $1.26 and $1.22 per pound, respectively, relative to supermarket branded products. CAB program parameters are listed in Table 6. In addition to the carcass quality parameters the program has a requirement for black hide that, in theory, would indicate some portion of Angus genetics.

Table 6: The quality requirements for beef to qualify for marketing under the Certified Angus Beef branded program (Siebert and Jones, 2013).

Modest or higher marbling
Medium to fine marbling texture
Under 30 months of age
10-16 square inch rib eye area
Carcass weight less than 1000 pounds
Less than 1 inch back fat
Superior muscling
No capillary rupture
No dark cutters
No neck hump greater than 2 inches

The Canadian Angus Ranchers Endorsed program endorses Canadian branded beef programs such as Spring Creek Angus Beef, and partners in this project, Heritage Angus Beef (HAB). The producers that market these branded products use feeder calves tagged with CAA RFID tags for which the requirement is a minimum of 50 percent Angus genetics. The program supports producers with branded beef programs source qualified feeder calves and market their branded beef product.

In addition to breed composition, some branded beef programs offer increased food safety attributes to consumers. Studies indicate cattle handled gently and humanely are less stressed and produce tender, quality beef (Newton, 2011). In Canada several branded beef programs, including Heritage Angus Beef, participate in the Verified Beef Production (VBP) program. VBP is Canada's verified on-farm food safety program for beef. It is a dynamic program designed to uphold consumer confidence in the products and good practices of Canada’s beef producers. VBP enhances the current reputation of

Canada's beef producers for acting responsibly. Grass-roots driven and industry-led, the program is part of a broader effort by Canada's food providers to ensure on-farm food safety and humane animal handling (VBP, 2008). The need to identify Canadian beef as safe and humanely raised in response to consumer demand was discussed at length in Section 2.1.3, VBP enables third party verification of this claim in branded beef product.

In the past decade, sales of meat products labelled as natural, minimally processed, and produced without added antibiotics and hormones have increased dramatically (Thilmany, Umberger, and Ziehl, 2006). The authors surveyed beef consumers in Colorado two thirds of who implicated production practices as important attributes that influence purchase decisions. HAB producers and their branded beef retail partners include breed composition, increased food safety, humane animal handling, environmental responsibility and no added hormones and antibiotics as attributes of their very comprehensive labelling. Figure 6 is an example of the labelling used by Hero Burger a retail brand supplied by HAB product.

Figure 6: A HAB supplied Hero Burger label certifying the beef product as Angus based, raised without the use of added hormones, antibiotics, in an environmentally sustainable and humane manner, and as fully traceable.

2. Brands convey value:

Schroeder's (2003) second reason for establishing brands in an industry is that consumers associate brands with value. Consumers perceive branded products to be more reliable, to have higher quality, and reduce the possibility for purchasing faulty products. Consumers tend to believe that if the person who produced a food product is willing to put his or her photo and name on the product, then that product is safer than a comparable product without such information (Clemens, 2003).

3. Branding builds loyalty:

Schroeder (2003) explains that building brand loyalty can increase profitability and that repeat sales require considerably less advertising and market development expense than marketing to a new customer segment. Thus, branding can impact overall system profit for reasons other than simply receiving a higher retail price. In addition, brand loyalty leads to greater market share when the same brand is repeatedly purchased by loyal consumers (Chaudhuri and Holbrook, 2001).

Patriotism also plays a significant role in consumer loyalty; most consumers have a higher trust level and identify with consumables produced in their own country. In Japan all imported meats face a consumer bias favouring domestic meats (Clemens, 2003). When surveyed, consumers from the United States, Canada, Germany, and the Netherlands also preferred domestically-made products foremost, followed by products made in other developed countries and, lastly, products made in developing countries (Okechuku, 1994). In fact, the closer to home: the better. When surveyed, Western Canadians generally preferred fresh beef products from Alberta to fresh beef products from other parts of Canada, and products from Canada are preferred to products from the United States (ALMA, 2012). These results support province and country of origin labelling for national markets.

The ABP's marketing campaigns are noteworthy as these campaigns represent sustained efforts by the industry to brand Canadian beef. In 1988 ABP launched its first campaign which was a series of photographs, postcards, and billboards featuring three cowboys leaning on a wooden fence in front of a mountain range, with the tagline "If It Ain't Alberta, It Ain't Beef" (ABP, 2008) In 2000 ABP modernized this campaign with “rancHERs” to target the female consumer. Their newest campaign, “Raised Right,” continues to promote Alberta beef as a safe quality product (Blue, 2009).

Surveys in international markets also strongly support labelling beef raised and processed in Canada. Although Tonsor (2011) found, in both online and in-person assessments, research participants regularly select meat products carrying origin information over unlabeled alternatives consistent with previous research, not all industries benefit from country of origin labelling. Roth *et al.* (2008) report that North American consumers are wary of purchasing products from China and other countries where food safety regulations may be less stringent, or perceived as less stringent, than in North America. The Canadian beef industry, despite the outbreak of BSE in Canada and other recent food safety scares, has established a reputation for being a source of safe high quality beef, perhaps due to the efforts of agencies such as CCIA, CBI and ABP. Branding Canadian beef as such should be a competitive advantage opportunity for the industry both locally, and in international markets.

Beef branding programs offer a means for satisfying consumer demand for high quality, differentiated beef products. Recent success of branded beef programs like CAB, and even smaller brands such as HAB, support the report by Martinez *et al.* (2011) that consumers search out these specific branded beef products as they expect a higher quality and are willing to pay a premium for it.

2.6 Existing traceability and vertical integration systems

Since the BSE crisis, many challenges have emerged for Canada’s beef sector particularly the industry’s ability to export beef product (Lewis, Krewski and Tyshenko, 2010). The BSE crisis in Europe and North America instigated a global realization that ‘you cannot manage what you cannot measure’ (Gooch and Sterling, 2013). Therefore, livestock identification systems were developed and implemented. Of the world’s eight largest beef exporters six have mandatory animal identification and tracking systems. Only the U.S. and India have not, to date, adopted a mandatory national animal identification system (Schroeder and Tonsor, 2011). Given that Canada exports 42 percent of its beef the ability to access global markets, and meeting the requirements of this access, is of significant importance to the Canadian beef industry (Myae, Goddard, and Aubeeluck, 2011).

The Canadian beef industry has in place a CCIA run cattle identification system which allows the industry to track animal movement through the production chain. This is the definition of traceability: the ability to verify the history and location of any animal in the system (Bowling *et al.*, 2008). There is an important distinction between identification, traceability, and label verification. Systems offering any or some of these attributes are typically implemented as a solution to demand for food safety management tools (Sanderson and Hobbs, 2006). Traceability is both a preventative strategy in food quality and safety management and, when hazards or food scares occur; a good traceability system will facilitate timely product recall and determination of liability (Hobbs *et al.*, 2005; Murphy *et al.*, 2008). Gooch and Sterling (2013) argue that traceability is achieved when a product or animal can be traced through a value chain back to it origin but also when the producer and upstream sectors can trace the animal or product to retail. This capability for full traceability is considered critical to addressing declining consumer confidence and general public concern about the rising incidence of food-related deaths and illnesses (Opara, 2003; Bowling *et al.*, 2008). In addition to quality and safety management, effective traceability systems can also deliver market benefits through product differentiation, label verification, and reduced cost of production through the ability to make more informed management decisions. Hobbs *et al.* (2005) report that different livestock identification and meat traceability systems have emerged in many countries, some of which are driven by the private sector and some are regulatory initiatives from the public sector that mandate livestock traceability. The 4 next sections will be dedicated to describing some of the systems currently in place globally. These systems support varying degrees of vertical linkage and integration.

2.6.1 Systems in the EU and Ireland

Livestock industries in the EU and Great Britain were devastated by the economic, political, and consumer confidence issues emanating from BSE and Foot and Mouth Disease outbreaks in the 1986 and 2001 respectively (Gooch and Sterling, 2013). In response, the EU introduced mandatory traceability and labelling initiatives involving national cattle identification and registration systems so that beef products can be labelled, and origin, birth, rearing, slaughter, and process information can be recorded (Bowling *et al.*, 2008; Hobbs *et al.*, 2005). The EU system is based on registration and tracking of cattle through a computerized database using a two ear-tag system. Animal identification options include the use of electronic identification devices such as RFID ear-tags, ruminal boluses and injectable transponders that automate the reading of animal identification numbers (Allen *et al.*, 2010). The system also requires each animal to have a passport which carries the corresponding tag or identification number, date of birth, breed, sex and mother's individual identification number. Passports accompany animals as they move down the production chain and are ultimately surrendered to state authorities at the packing plant (Hobbs *et al.*, 2005).

Private industry in some EU countries use the mandatory animal identification and animal movement tracing systems as a spring board for more extensive traceability programs. One of the more successful companies IdentiGEN Ltd (www.identigen.com) offers a system called TraceBack® which uses DNA markers to track animals through the value chain to the point of the retailer. Figure 7 shows the basis of the TraceBack® system which is employed by the Irish Farmers Association and a large retailer, SuperValu, to verify the country of origin labelling on Irish Pork.

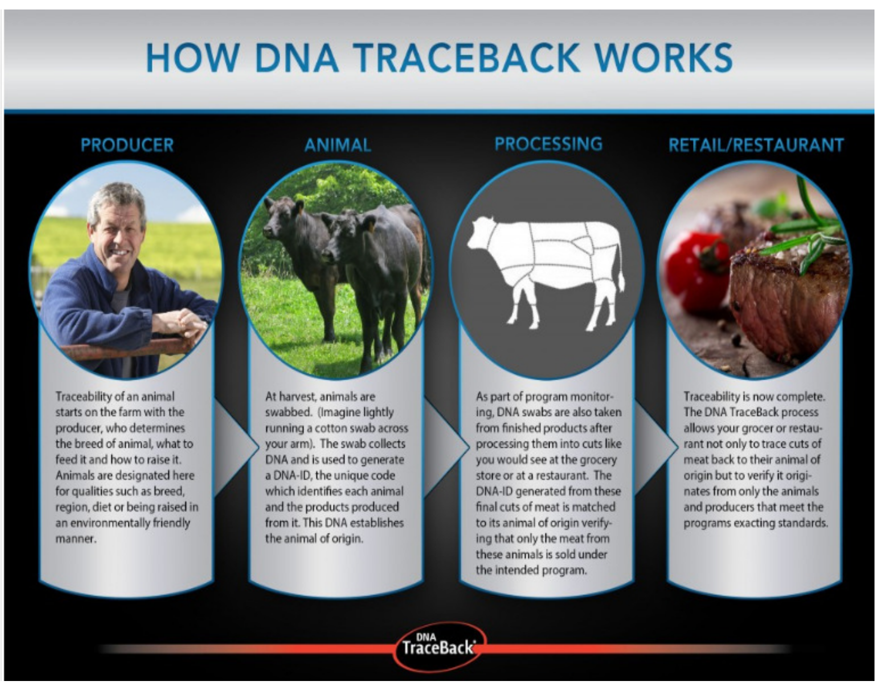

Figure 7: The program schematic for a popular animal traceability system, TraceBack®, used in Irish livestock industries to link meat product from gate to plate (IdentiGEN, 2013).

In a press release dated August 29th 2013, IdentiGEN stated that as a result of the weaknesses found in the paper-based traceability system following the pig meat dioxin crisis, the Irish Farmers Association partnered with the company to create the world's first national DNA database for pigs using the TraceBack® system (IdentiGEN, 2013). In 2012 the Aberdeen Angus Cattle Society (a Breed Association) aligned itself to use IdentiGEN's TraceBack® system for verification of product marketed through its branded beef program: Certified Aberdeen Angus Beef (IdentiGEN, 2013).

2.6.2 Systems in Japan and South Korea

The Japanese government and food industry have adopted parts of the European post-BSE model to alleviate consumer fears and rebuild consumer confidence in the safety of the food supply. All cattle require a tag with a unique animal identification number and animal movement must be recorded into a government maintained database (Schroeder and Tonsor, 2011). Producers must also submit, for each animal, breed, sex, and date of birth. Subsequent animal information including feed consumed and medical treatment administered is submitted by the feedlot, and animals are tracked from the feedlot to the packing plant (Clemens, 2003; Bowling *et al.*, 2008). In addition to all this, in South Korea inspectors at the packing plants record the carcass quality and yield grade for each animal. South Korean producers can access this information for subsequent breeding and management decisions (Bowling *et al.*, 2008).

The focus of the Japanese and South Korean traceability systems was to gain consumer trust and confidence in beef products (Schroeder and Tonsor, 2012). Therefore, beef consumers in both countries can access the date of birth, sex, carcass quality, producer, feed and treatment information. The Japanese and South Korean traceability systems are designed to allow consumers to enter the unique ten digit animal identification number that is provided on the label of retail beef and access information about where the animal was raised, its sex, breed, date of birth, locations where it was raised and slaughtered (Schroeder and Tonsor, 2012).

2.6.3 Systems in Australia and New Zealand

Australia and New Zealand both have independent animal identification systems based on two ear tags or a rumen bolus with unique animal identification numbers. These are assigned to premise identification codes as they move through the beef production chain (Bowling *et al.*, 2008). The two national livestock identification systems are also being used as a springboard for more extensive quality assurance programs. One system provides consumers with information on the disease and pharmaceutical residue status of animals, another system provides consumers a level of quality assurance (Lawrence, Schroeder, and Hayenga, 2001; Hobbs *et al.*, 2005). According to Bowling *et al.* (2008), unless specific agreements are reached between producers and harvesting facilities, animals are grouped into lots by harvest date and time, and individual animal carcass quality data is not available. Producers in Australia and New Zealand both can either make general management decisions based on group carcass information, or establish relationships and agreements with their packing plant to receive individual carcass quality information on their feeder calves in order drive genetic selection in future generations.

2.6.4 Systems in the U.S. and Canada

Although the U.S. sheep and pork industries both have a national mandatory animal identification and premise identification recording system, the U.S. beef industry, despite the benefits of livestock disease monitoring and ensuring food safety, still maintains a national animal identification system that is voluntary (Murphy *et al.*, 2008). U.S. animal identification tags have been used successfully in the past to help eradicate brucelloisis from cattle, scrapie from sheep and pseudorabies from swine. None the less, the U.S Department of Agriculture (USDA) only recommends that beef producers participate in the national animal identification system which essentially generates a unique premise identification number for each registered ranch. Subsequent animal identification systems, using USDA-recognized tags or other devices, are offered and maintained by private industry (Murphy *et al.*, 2008).

In Canada the CCIA has run a mandatory animal identification system since 2002. This system is designed primarily to deliver a reactive traceability function: facilitating the trace back of animals or food products in the event of a food safety or herd health problem (Sanderson and Hobbs, 2006). Cattle leaving the herd of origin are issued a unique RFID tag (see Section 1.2.2) and animal identification number that remains with the animal to the point of carcass inspection in the packing plant (Myae, Goddard, and Aubeeluck, 2011). In the event of a food safety problem, information on the last location (by premise identification) of the animal and the herd of origin is used to track cattle movements both backward and forward in the supply chain (Hobbs *et al.*, 2005 and Murphy *et al.*, 2008).

The CCA, in recognition that most Canadian beef producers have little idea how their animals perform once they are sold, developed the Beef information Exchange System (BIXS) system. The system is based on tying animal-specific information to the CCIA tag. Participating producers can enter animals into the system by going online and recording their calves' birth date and tag number in their BIXS account. Feedlots would submit move in and out dates as well as growth and animal health records. Once the animal is slaughtered the packer uploads yield and grade information (McClinton, 2010). The premise of this system is that each sector can access this information for personal knowledge and to benefit of the Canadian beef industry. This is a voluntary system that has gained some traction in the Canadian beef industry in the past few years. The DNA tracking system designed and demonstrated within this project has the capability for information exchange with BIXS as it may be a good source of feeder calf information. The DNA tracking system brings value to the feeder calf information by tying it to sire genetics and presenting the data to commercial producers in a format that is easy to interpret.

Numerous branded programs in the U.S. and, to a lesser extent Canada, undertake traceability for the purpose of production and process verification from farm to packer (Sanderson and Hobbs, 2006). Branded beef programs such as CAB and HAB obtain premiums for products that address the demands by consumer market segments for specific food quality and safety attributes. However, within these systems individual animal identification is still not retained post-slaughter in most major packing plants (Sanderson and Hobbs, 2006). This post slaughter gap in identification makes systems that use DNA in conjunction with animal RFID numbers to track product beyond the packing plant increasingly effective.

IdentiGEN's TraceBack® system has been adopted by several branded beef programs in the U.S. and in Canada. Loblaw's Ontario Corn Fed Beef program applies the TraceBack® system to verify its label attributes for its consumers. Kosher beef consumers in New York, Florida and California can also purchase Aurora Kosher Choice Beef® which is verified by the DNA TraceBack® (IdentiGEN, 2013).

Few of the systems described in this Section deliver true vertical integration where information flows both downstream for product differentiation and also upstream for application towards genetic improvement. IdentiGEN has partnered with the Atlantic Veterinary College at the University of Prince Edward Island in a project to use the TraceBack® system to identify parentage of individual pigs in order to make associations between incidences of on-farm swine mortality and genetics (IdentiGEN, 2013). This linkage of health information with boar genetics will allow Canadian pig farmers to select for improved health response. Similarly, another service provider, Cow Calf Health Management Services (CCHMS), is linking calf performance information to parental genetics. CCHMS uses a software system called HerdTrax that has the capability of housing feeder calf performance information and generates mating suggestions based on this data, provided that the parentage of the feeder calves is known (CCHMS, 2013).

Traceability systems that provide animal identification and animal movement tracking solely to fulfill legal requirements are reactive insurance-like systems. Traceability systems that also allow for product differentiation and genetic improvement deliver a competitive advantage (Sosnicki and Newman, 2010).

2.7 Animal identification technology

Historically, animals have been identified using brands, ear tattoos and ear dangle tags. Recently, RFID technology has been adopted to identify both domestic and wild animals globally (Allen *et al.*, 2010). The radio frequency capabilities can be divided into two classifications, high frequency (13.56 MHz) or low frequency (125-134.2 kHz) (Voulodimos *et al.*, 2010). The latter is more commonly used in domesticated livestock industries because there are readability challenges with RFID technology. Shanahan *et al.* (2009) recommend biometric animal identification technologies such as retinal scans which also present practicality challenges. However, animal mis-identification resulting from tag loss has profound epidemiological and traceability implications which can result in costly consequences for beef industries (Allen *et al.*, 2010). EU animal identification requirements include two ear tags, one in each ear to minimize the impact of tag loss (Bowling, 2008; Hobbs *et al.*, 2005). Similarly, there are deficiencies in meat labelling at packing plants and retail facilities (Allen *et al.*, 2010). The authors report on a recent DNA traceability study which indicated that 2 percent of randomly selected samples from labelled carcasses at the abattoir did not match the profiles of the animals they were purported to come from. This increased to 3 percent when sampling was conducted at the point of sale (Allen *et al.*, 2010). DNA profiling, which utilizes unalterable biological properties of individual animals to produce a unique identifier, offers a potential solution to this challenge.

Historically, DNA testing has been reported as being too slow and costly to be used for routine identification of livestock (Shanahan *et al.*, 2009). Presently, the technology to read DNA profiles (genotype animals' DNA) in real-time does not exist. However, this only limits the use of DNA as a primary identifier of animals and derived food products (Allen *et al.*, 2010). If used in conjunction with RFID ear tags, an animal's unique DNA profile can be an effective tool for animal and product identification. According to Allen *et al.* (2010) the added advantage of using DNA in an animal tracking system is that it can be used effectively in retrospective audits to verify tag identity. And, DNA based parentage verification makes it a powerful method for linking progeny performance to the breeding stock sector.

Historically, short tandem repeats (STRs), also known as Microsatellites or restriction fragment length polymorphism (RFLP) markers, approved by ISAG, have been used for parentage verification in livestock (Allen *et al.*, 2010). The recent sequencing and publication of the bovine genome and the identification of single nucleotide polymorphisms (SNPs) have provided new tools for animal identification and parentage verification (Lobo *et al.*, 2011). These advancements in DNA technology have replaced low-throughput, time consuming and difficult to score assays to the newest high-density SNP assays that are easily and inexpensively generated (Rolf *et al.*, 2010). The USDA and ISAG now recommend SNP technology for use in animal identification and parentage verification (Allen *et al.*, 2010). The ISAG Cattle Molecular Markers and Parentage Testing committee used pedigree and genotype information from 4000 animals to determine that 100 well chosen SNPs from the 121 SNPs recognized by the USDA for their high linkage disequilibrium has the power to make accurate parentage verification calls based on a maximum of 2-3 mismatches for one parent and 3-4 if both parents are known (ISAG, 2012). SNP technology is robust and also versatile: it has been used in the Canadian dairy and pork industries to help manage deleterious genetic conditions and incorporate genomic SNP markers for the calculation of more accurate EPDs (Plastow *et al.*, 2003).

Chapter 3: The Design and Demonstration of a DNA Tracking System for the Canadian Beef Industry

3.1 Introduction

This DNA tracking system was designed to trace genetics through the beef production chain. The starting point of the industry is typically at its nucleus, the seed stock sector, where breeding bulls and replacement females are raised. Pedigree records and SNP parentage verification genotypes for Canadian Angus seed stock are stored at the Canadian Angus Association, and are the basis of this system. In 2012, CAA members invested 107,489.74 dollars in DNA technology for parentage verification (CAA, 2013). The CAA uses a 105 SNP chip for parentage verification to meet ISAGs recommendation to parent verify using 100 SNP markers. There are an additional 5 SNPs on the Association panel to offset gaps in genotyping. The 105 SNP markers are a subset of the 121 SNP markers recommended by the USDA for parentage verification in bovine (Allen *et al.*, 2010; ISAG, 2012).

As breeding stock move into the commercial sector commercial producers are able to use their SNP parentage verification genotypes to determine which bulls sired their calves born in multisire pastures. As feeder calves change ownership down the value chain the system bridges gaps in knowledge about the calves' performance by tracking them through the feedlot where growth and health records are collected. DNA sampling of feeder calves can occur either on the commercial ranch, or upon entry at the feedlot.

Finished calves are followed to the packing plant where carcass quality is measured and recorded. The system then delivers feeder calf performance information, with sire determinations, in a manner that is applicable to breeding programs for more holistic and accurate genetic selection. In turn, beef product at the packing plant is also sampled and linked using DNA technology to calves and their management records in order to obtain label verification. The contribution of each sector of the industry into the program is shown in Figure 8.

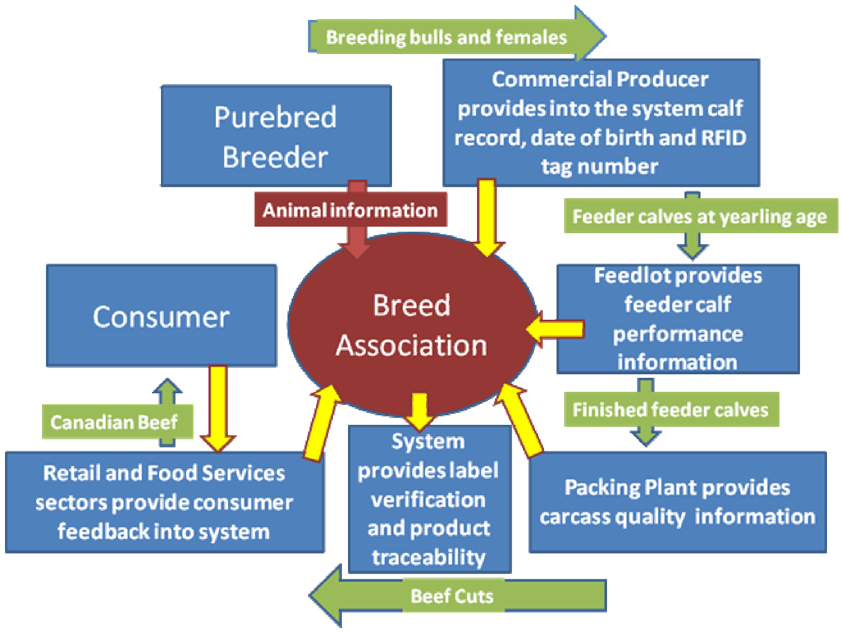

Figure 8: A depiction of the Canadian beef industry sectors, the flow of product down the production chain, and the information that each sector participating in this DNA tracking system would provide.

The demonstration of this system provided an opportunity to assess DNA sampling and genotyping technology for economic merit and practicality. Technology assessed for practicality in various environments and conditions will minimize barriers to system adoption. In addition, the demonstration of this DNA tracking system offered the opportunity to establish a minimum sampling threshold for the purposes of label verification and auditing of branded beef programs. Essentially, the determination of a minimum sampling threshold would enable producers to sample only a proportion of cut beef product as opposed to having to sample 100 percent of the retail product to verify its label. There might be significant cost reduction associated with the determination of a minimum sampling threshold. Error rates in DNA extraction, genotyping, and linking DNA from cut beef to calves from the HAB program established during the demonstration will aid in the calculation of this minimum sampling threshold.

3.2 Hypothesis and research objectives

This project aimed to test the hypothesis that high throughput DNA technology and the Canadian Angus Association SNP parentage verification database could be leveraged through a DNA tracking system to report feeder calf parentage and performance information for use towards genetic improvement, and that the same technology could be used to link animal and animal management attributes to cut beef for value added label verification.

Specific components of a successful DNA tracking system would include:

1. Use of the CAA SNP parentage verification genotype database and high throughput DNA analysis technology to identify sires for feeder calves from multisire pastures.
2. Technology that is both cost effective and practical at the farm, feedlot, packing plant and laboratory to ensure adoption and continued usage in the Canadian beef industry.
3. Electronic information transfer to access feeder calf performance data either directly from the various sectors of the Canadian beef industry or through existing industry systems such as BIXS and HerdTrax.
4. Delivery of feeder calf performance information to seed stock breeders and commercial producers in the form of Sire Production Summaries for effective genetic selection.
5. Use of high throughput DNA technology to link branded beef product to the calf it came from thereby verifying product differentiation and the label.
6. Establishment of a minimum sampling threshold to ensure affordability of the label verification portion of the system.

3.3 Project partners

This project was designed to bring together industry partners from different sectors of the beef production chain. As such, there was an opportunity to test if such a system could help integration across the beef value chain. Partners that supported this project included the Canadian Angus Association, Calgary AB, Heritage Angus Beef Producers AB, Hagel Feedlots, Linden AB, Canadian Premium Meats, Lacombe AB, Delta Genomics, Edmonton AB, Livestock Gentec, Edmonton AB, and ALMA, Edmonton AB.

The Canadian Aberdeen Angus Association (CAA) was incorporated under the federal Animal Pedigree Act as a not-for-profit Breed Association in 1906 with the directive to register Angus pedigrees (CAA, 2013). Today, the Association represents 3,719 seed stock breeders across Canada for the purposes of registering and recording the pedigrees of purebred Angus cattle and promoting the breed across Canada. Its member approved mandate is to maintain the breed registry, breed purity and provide services that enhance the growth and position of the Angus breed. Canadian Angus cattle have had a significant impact on the Canadian beef industry. At approximately 60,000 calf registrations a year, the breed currently accounts for more than 54 percent of all purebred registrations in Canada (CAA, 2013). Based on 2009 auction market statistics, more than 68 percent of all beef cattle in Canada are either Angus or Angus influenced (CanFax, 2013). The breed's influence in the U.S. beef market is just as significant. The American Angus Association registered 315,007 calves in 2012 (AAA, 2013). In addition, 75 percent of the branded beef programs in the U.S. are based on the Angus breed as an attribute (Smith *et al.*, 2006). One of the world's largest branded beef programs is Certified Angus Beef (CAB) which consumers associate with quality (Siebert and Jones, 2013).

Several seed stock breeders, members of the Canadian Angus Association, sell breeding bulls to Heritage Angus Beef (HAB) Producers, a cooperative of commercial producers who have developed an integrated Canadian beef production system for highly differentiated and labelled HAB. These Alberta producers are committed to raising cattle using no added hormones, antibiotics or animal by-products, using native and tame pastures on land unsuitable for most crops (Weder, 2013). HAB markets all natural Alberta beef in North America, the Middle East and Europe. In North America, HAB is sourced by groups such as Hero Burgers, Toronto, ON, Two Rivers Meat Shop, Vancouver, BC, and Prairie Halal Foods, Camrose, AB. These groups retail premium products and are increasingly demanding label verification and some level of traceability for their premium product (Weder, 2013).

HAB cattle are fed exclusively by Hagel Feedlots in Linden AB. Hagel Feedlot is a fourth-generation central Alberta farm that has been custom feeding cattle since 1995. They grow and feed organic hay, alfalfa, barley silage and barley to raise natural beef without antibiotics, growth hormones, or animal by-products. Both HAB producers and Hagel Feedlots are active members of the Verified Beef Production (VBP) program that promotes management for animal health and welfare (VBP, 2008). Hagel Feedlots specializes in managing healthy animals that gain comparably to animals fed at other non-natural facilities. They are also an advocate of recording performance information:

they maintain average daily gain, health treatment, and days on feed records for all HAB cattle. Once finished, HAB cattle are slaughtered at Canadian Premium Meats (CPM).

CPM is a midsized capacity (see Table 3) packing plant located in Lacombe, AB. It is certified by the Islamic Society of North America for the production of Halal product, and certified by ECO-Cert to process organic beef. The packing plant is approved and certified to process meat for distribution in the Canadian market as well as for export to China, the EU, Hong Kong, Korea, Russia, Singapore, Taiwan, the United Arab Emirates, the U.S., and to Vietnam (CPM, 2013).

Delta Genomics, Edmonton, AB, is a national, not-for-profit genomics service provider created as the service arm of Livestock Gentec (below). The laboratory provides biobanking, genotyping, and sequencing services for members of both the livestock industry and livestock research community. Delta's biobanking service offers storage for a wide range of sample and specimen types, including blood, semen, hair, and tissue. Delta has the capacity to store samples at different temperatures as some samples require storage at room temperature while others require storage at minus 80 degrees celsius. In addition, Delta has a Laboratory Information Management System (LIMS) data storage system capable of tracking and retrieving hundreds of thousands of samples. This LIMS system has been programmed to interface with the CAA system for seamless electronic transfer of information increasing efficiencies between the partners.

Delta is set up to perform high throughput automated DNA extraction through the use of its QIAsymphony system and BioSprint (Qiagen) automated extraction instruments. Delta has two distinct platforms that it can use for parentage genotyping, the Sequenom MassARRAY and the Illumina BeadExpress systems. Both these systems are used for high throughput DNA analysis and can measure up to 3,000 markers at a time. Delta's parent institute Livestock Gentec is an Alberta Innovates Bio Solutions centre based at the University of Alberta. Livestock Gentec directs research and aims to bring the commercial benefits of genomics to the Canadian livestock industry (Livestock Gentec, 2013). The Centre plays a critical role in bringing together the research community, industry partners and livestock producers.

Funding support was provided by ALMA, a provincial government agency established to help advance Alberta's livestock and meat industry.

3.4 Materials and methods

The existing CAA commercial database where CAA RFID numbers are associated to producers, their CCIA registered premise identification numbers, and their calves was expanded to accommodate calf information beyond RFID number and date of birth. As indicated in Figure 8 the system database would need to house feeder calf performance information from the feedlot sector, carcass quality information from the packing plant sector, and sire information based on SNP parentage verification information from the laboratory. The CAA commercial database was programmed to receive this information electronically, either directly from these sources, or using industry systems such as BIXS and HerdTrax.

Having consulted with, and identified producers' primary requirements for information, Sire Production Summaries were designed to provide seed stock breeders and commercial producers average feeder calf performance information in a format that supports selective breeding. Figure 9 shows a prototype of the report design and illustrates the information that would be available for producers to make subsequent breeding decisions.

Canadian Angus Association

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Sire Commercial Production Summary

Owner: **Keeler Feedlot**	Rego# and Name: **CP243984993**	Date Issued: **05/11/2013**
Address: **PO Box 569 Raymond AB T0K 2S0**	RFID #: **124000243984993**	Tag: Tattoo:
Sire's Reg# and Name:		Birth Date: **01/01/2000**

			Calf Average Carcass Information							
			Live	Hot	Cold	Hot Yield	Grade	Yield	Dof	Adg
Calves' Average Performance Details	Male	7	-	-	-	-	-	-	-	-
	Female	10	-	-	-	-	-	-	-	-

Black Angus EPDs for														
	Birth Weight	Weaning Weight	Yearling Weight	Milk	Total Maternal	Calving Ease	Mat. Clv. Ease	Scrotal Circ.		Marbling	REA	Fat	CWT	
EPD														
ACC														
Black Average	+2.8	+41	+74	+19	+39	+2.4	+5.6	n/a	n/a	+0.28	+0.19	+0.010	+21	n/a

Figure 9: A prototype of the Sire Production Summary that seed stock breeders and commercial producers participating in this DNA tracking system would receive, reporting the average performance of calves SNP parent verified to the sire, and the sire's Breed Association EPDs.

3.4.1 DNA sample collection

Participating producers identified 251 bulls to be potential sires of the calves used in this project. Typically, registered Canadian Angus bulls would already be DNA sampled and genotyped for SNP parentage verification markers through the Association; that is the basis of the DNA tracking system. However, because several of the producers participating in the demonstration were using old bulls that had not been genotyped, or unregistered bulls, only 102 bull DNA samples and parentage verification genotypes were available through the Association. DNA samples were collected for an additional 96 potential bulls on farm. Figure 10 is a collage of sample collection methods and technologies that were evaluated during the demonstration. These include hair samples, the Allflex NextGen tissue sampling units (TSU) and sampler, and the Typifix tissue collection tag and sampler. DNA samples for 53 potential sires were not available.

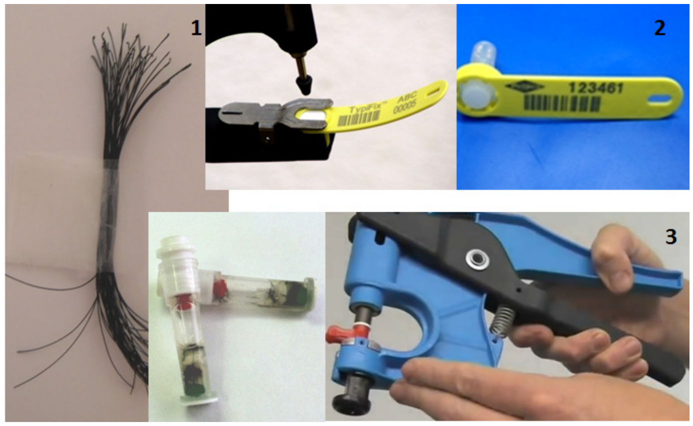

Figure 10: The three animal DNA collection technologies that were assessed during the project, including hair root bulb (1), Typifix tissue collecting tags (2), and Allflex NextGen TSUs (3).

Within the test system, calves can be sampled either at the ranch or at the feedlot. For the purposes of this demonstration 1,237 calves were DNA sampled upon entry at the feedlot, 765 using the Allflex NextGen TSUs, 200 using the Typifix tags, and 272 calves were DNA sampled by pulling hair. DNA samples were subjected to environmental temperatures ranging from +24 to -31 degrees Celsius as they were transported to the laboratory.

DNA samples for 249 cuts of HAB product were collected at CPM after carcasses were quartered and the Angus RFID tag was removed from the carcasses. This ensured random sampling. Three different technologies (see Figure 11) were used to sample the meat product. DNA samples taken using the IdentiGEN meat scraper, a patented tissue sampling tool, were captured by gently rubbing the uncapped tip of the sampler against cut beef and then recapping the sample. Cut beef was also DNA sampled using sterile tongue depressors and plastic knives by scraping one end gently along cut beef and the isolating each sample in sterile ‘ziplock’ bags.

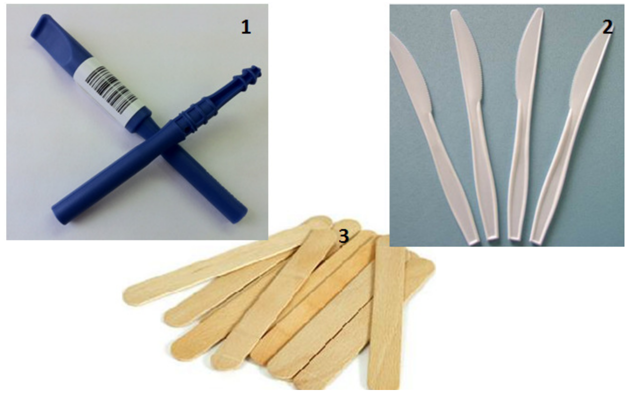

Figure 11: The three beef product sampling technologies assessed within this project, including the IdentiGEN meat scraper (1), plastic knives (2) and tongue depressors (3).

3.4.2 DNA extraction

DNA extraction was performed at Delta Genomics which is set up to perform high throughput automated DNA extraction through the use of its QIAgen BioSprint automated extraction instrument. The quality of the DNA extracted using the Qiagen system is very high, and yielded enough DNA to perform multiple analyses. Hair samples were digested using a 10 percent (v/v) solution of Qiagen Proteinase K in buffer ATL for 16 hours, usually overnight. Subsequently, DNA was extracted from hair, semen and tissue samples using the Qiagen BioSprint 96 DNA Extraction Kit (Cat no. 940057) and the Qiagen BioSprint automated DNA extraction machine as per manufacturer's instructions. This automated process takes approximately 30 minutes per 96 samples.

3.4.3 Genotyping

DNA from sires that did not already have SNP parentage verification genotypes on file with the CAA was genotyped at Delta Genomics using the Infinium Whole-Genome Genotyping chemistry on the BovineSNP50 version 2C marker panel with the Illumina HiScan machine. Genotypes for the 105 SNPs were extracted from this larger data set of 50,000 SNPs. In parallel, DNA from the sires was genotyped at Delta Genomics using the Sequenom MassARRAY and at Eureka Genomics, Hercules, CA using Next Generation Sequencing technology. The latter is new technology that has not yet being commercialized. Eureka Genomics is a global leader in developing Next Generation Sequencing (NGS) based assays. Their technology platform uses proprietary software and algorithms to deliver comprehensive DNA analysis (Curry, 2013). In brief, Eureka employs a method called Next Generation Genotyping (NGG) that involves PCR amplification of target loci to create DNA libraries readable by next-generation sequencers at extremely low cost-per-sample. DNA samples for the feeder calves sampled at the feedlot were also genotyped at Eureka. DNA from 192 of these was genotyped in parallel using the Sequenom MassARRAY system at Delta Genomics as an additional opportunity to validate and assess the NGG from Eureka.

3.4.4 Parentage verification

Sire group information supplied by producers was used to organize calf genotypes and their potential sires. Each SNP locus for a calf is compared to the genotype at the same locus for every potential sire to determine if the sire has at least one allele in common with the calf. Multiple loci are analyzed this way until the best possible match (i.e. least number of 'impossible' inheritances) is identified, and parentage is assigned at a certain threshold value of genotype matches. Table 7 lists the genotypes of three bulls and a calf for ten parentage verification loci. Of these three potential sires, Sire 1 qualifies as the sire of the calf with greatest confidence. In this example, Sires 2 and 3 are mismatched with the calf's genotype at two different loci.

Table 7: SNP parentage verification genotypes at 10 loci for a calf and its 3 potential sires as an example of the process of sire verification, Sire 2 and Sire 3 both have 2 mismatches from the calf's genotype at loci AY939849 and AY856094 and at loci AY858890 and AY856094 respectively, Sire 1 qualifies to this calf with 0 mismatches and a 100 percent confidence.

	AY776154	AY841151	AY842472	AY858890	AY914316	AY857620	AY939849	AY860426	AY863214	AY856094	Mismatches	Confidence
Calf	AG	CC	CG	GG	AA	CG	AA	CC	AA	GG		
Sire 1	AG	CC	GG	GG	AC	CC	AA	CC	AA	AG	0	1
Sire 2	AA	CC	CG	CG	AC	CG	**GG**	AC	AA	**AA**	2	0.82
Sire 3	AG	AC	CG	**CC**	AC	GG	AG	AC	AA	**AA**	2	0.82

To account for analysis error, ISAG recommendations state that high confidence in parentage verification can be based on 2-3 mismatches if only one parent genotype is known. For the purposes of this system sires were qualified to calves based on 5 or less mismatches, and a minimum confidence level of at least 0.95 (95 percent).

3.5 Results

This project resulted in the design of a DNA tracking system which was then demonstrated to the Canadian beef industry in partnership with the participating producers and industry partners. The results from the demonstration of the DNA tracking system are reported below. The demonstration provided the opportunity to assess DNA sampling technology at the farm, feedlot, packing plant laboratory level. High throughput genotyping technology was also assessed. The demonstration also provided some statistics with which a minimum sampling threshold could be calculated for the label verification portion of the system.

3.5.1 Evaluation of DNAsampling technology for efficacy

At the farm level, all participating producers preferred to pull hair root bulbs which resulted in successful DNA sampling of the potential sires DNA sampled for the project. During the demonstration DNA sampling feeder calves by: pulling hair from the tail switch, using Allflex NextGen TSUs, or Typifix tags to collect tissue samples were assessed for practicality and cost effectiveness. At the packing plant level the three DNA sampling technologies evaluated included the IdentiGEN meat scraper, sterile tongue depressors, and sterile plastic knives. Table 8 details the assessment of the 6 different sampling techniques for cost, time per DNA sample capture, ease of sampling, and ease of transportation.

Table 8: A comparison of the ease and cost of using three different DNA sampling methods for live cattle, and three different DNA sampling methods for cut beef.

Technology	Sample type	Cost per unit ($)	Time per sample (sec)	Ease of sampling	Ease of transportation
Animal Sampling					
Envelope or 'ziplock' bag	Hair	0.10	> 30	Fair	Easiest
Allflex TSU	Tissue	3.33	< 30	Easy	Easy
Typifix Tag	Tissue	2.50	< 30	Easy	Easy
Tissue Sampling					
IdentiGEN scraper	Tissue	5	< 30	Easiest	Easy
Tongue depressor	Tissue	0.10	> 30	Challenging	Easy
Plastic Knife	Tissue	0.10	< 30 sec	Challenging	Easy

At the laboratory, 3 Typifix tags were empty of DNA sample, and 2 of the DNA samples taken using Allflex NextGen TSUs were spoilt. In addition, 96 DNA samples from feeder calves DNA sampled using the Allflex TSUs were lost when a 96 well plate was accidentally dropped. Extracted DNA concentrations for the 1136 DNA samples from the feeder calf within the project ranged from 0 to 907ng/ul. Of these, 96.3 percent (1094) samples met the minimum extracted DNA concentration requirement for genotyping through Eureka Genomics (1.23ng/ul). Table 9 summarizes the efficacy of the different sampling technologies in the laboratory. Tongue depressors and plastic knives were not evaluated at the laboratory as the two methods were abandoned as impractical within the first few samples taken.

Table 9: Assessment of different DNA sampling technologies trialed in this project at the laboratory; hair samples and Allflex and Typifix tissue collection technologies were used to DNA live animals and the IdentiGEN scraper was used to DNA sample cut beef. These four technologies were assessed at the laboratory for DNA concentration, failure rates, processing time and ease of biobanking.

Technology	Typical DNA concentration (ng/ul)	Failure rates	Processing time	Biobanking
Hair	100	3%	1 day + 16 hours digest	Easiest
Allflex TSU	100	5%	1 day	Only 1 extraction possible
Typifix Tag	150	4%	1 day	Only 1 extraction possible
IdentiGEN scraper	150	4%	1 day	Only 1 extraction possible

3.5.2 Evaluation of genotyping technologies

A comparison of the different genotyping platforms is shown in Table 10. Delta Genomics evaluated genotyping for the different parameters using the Infinium Whole-Genome Genotyping chemistry on the BovineSNP50 version 2C marker panel with the Illumina HiScan machine, using the Sequenom MassARRAY, and using NGG at Eureka Genomics.

Table 10: A comparison of the Infinium Whole-Genome Genotyping chemistry on the BovineSNP50 version 2C marker panel with the Illumina HiScan machine, using the Sequenom MassARRAY, and using NGG by Eureka Genomics for cost, processing time, accuracy, DNA requirements and limitations of the technology.

	Illumina	**Sequenom**	**Eureka**
Cost ($)	85	15	10
Time	192 in 3 days	384 in 3 days	1600 in 8 days
Accuracy (%)	99+	99+	99+ (validation)
DNA requirement	5 ng	2 ng	1.23 ng
Limitations	Minimum 48 samples	Minimum 192 samples	Minimum 1000 samples

3.5.3 Parentage calls

Correlations of over 99 percent were achieved for the 192 samples that were run in parallel using the Sequenom MassARRAY at Delta and NGG at Eureka. Of the 1,237 calves that were DNA sampled for the project, total of 1,094 DNA extractions met Eureka Genomics' minimum DNA concentration requirements. Of these 1,094 extracted DNA samples that were sent to Eureka Genetics for genotyping, qualified sires were identified for 89.6 percent (or 980 calves). These were based on best fit within the sire groups identified by producers. For the purposes of this DNA tracking system, parentage qualifications were based on a maximum of 5 mismatches or 95 percent confidence. On average, only 37 percent of the calves sampled were assigned a sire at the confidence level that was selected for this system. For 10.4 percent (or 114) of the calves that were genotyped none of the breeding bulls genotyped shared enough common SNPs for parentage verification loci to qualify as potential sires.

3.5.4 Generating sire commercial production summaries

Having attributed the DNA verified sire and performance information to each feeder calf in the demonstration, the system was populated with sire information and performance information for each calf in order to generate Sire Production Summaries for the participating producers.

Canadian Angus Association

#142, 6715 - 8th Street NE, Calgary, Alberta, T2E 7H7 Ph: (403) 571-3580, Fax: (403) 571-3599, Toll-Free: 1-888-571-3580, Email: registry@cdnangus.ca

Sire Commercial Production Summary

Owner: **Shoestring Ranch** Rego# and Name: **1391468 MAF NETWORK 10T** Date Issued: **06/10/2013**

Address: **PO Box 321**
Acme AB T0M 0A0

Tag: **10T**
Tattoo: **LCE 10T**

Sire's Reg# and Name: **1309743 S A V NET WORTH 4200** Birth Date: **20/02/2007**

			Calf Average Carcass Information							
			Live	Hot	Cold	Hot Yield	Grade	Yield	Dof	Adg
Calves' Average Performance Details	**Male**	25	1244.9	730.0	715.6	58.66	AAA	2	168	2.82
	Female	5	1302.1	765.1	750.8	58.71	AAA	2	190	2.72

Sire Commercial Production Summary

Owner: **Shoestring Ranch** Rego# and Name: **1595859 MAF DENSITY 41W** Date Issued: **06/10/2013**

Address: **PO Box 321**
Acme AB T0M 0A0

Tag: **41W**
Tattoo: **LCE 41W**

Sire's Reg# and Name: **1266311 S A V 004 DENSITY 4336** Birth Date: **20/02/2009**

			Calf Average Carcass Information							
			Live	Hot	Cold	Hot Yield	Grade	Yield	Dof	Adg
Calves' Average Performance Details	**Male**	2	1186.1	712.8	697.5	60.11	AAA	2	176	2.55
	Female	0	-	-	-	-	-	-	-	-

Figure 122: An example of a Sire Production Summary generated for producers participating in this demonstration of this DNA tracking system that outlines the average performance of two bulls for number of calves, carcass quality traits and feedlot growth for use in subsequent breeding decisions to drive genetic improvement for these traits.

The Sire Production Summaries detail for each bull the number of calves each bull sired, and (separated by sex) the average live weight, hot and cold carcass weight, lean meat yield and yield grade, marbling grade, days on feed and average daily gain of the sire’s calves.

3.5.5 Label verification

Of the 249 cut beef DNA samples that were taken using the IdentiGEN meat scraper 89 percent (222) samples were successfully genotyped. Only 37 percent (82) samples of beef cuts were matched to feeder calves registered and sampled within the program. It is possible that the 185 unmatched samples were from the 96 calves for which samples were lost in the laboratory (see section 3.5.1). However, there is also a possibility that calves that were not sampled as part of the program were included in the HAB product.

The demonstration of this DNA tracking system allowed for the calculation of environmental and laboratory error rates that would typically occur. An 11.44 percent error rate was associated with the process of DNA sampling of calves and beef cuts, extracting DNA of concentrations above 1.23ng/ul, and genotyping the DNA for SNP parentage verification markers.

Total number of DNA samples:	1237 + 249 = 1486
Total number genotyped successfully:	1094 + 222 = 1316
Error Rate:	1316 / 1486 x 100 = 88.56
	100 – 88.56 = 11.44 %

The minimum sampling threshold was estimated with the help of Dr. Brian Kinghorn, University of New England, Armidale, Australia. For a 95 percent level of confidence the following power calculation was applied to the results obtained in the demonstration.

$$0.95 = 1 - (1-0.05)^{x}$$

$$x = \log(1-(1-0.01))/\log(0.95)$$

$$x = 59 \text{ samples}$$

If, 95 percent of the HAB cuts were in fact from Heritage Angus Beef program calves that were sampled at the feedlot then as shown above sampling 59 random cuts of beef would result in the inclusion of one non program sample. This assumes that all the calves sampled and all the beef cuts samples would be successfully genotyped. Results from the demonstration of the DNA tracking system imply the need for inclusion of an error rate of 11.44 percent as only 88.56 percent of the DNA samples taken during the demonstration were successfully genotyped (this would have been 96 percent had the 96 well plate not been dropped at the laboratory).

$$11.44\ \%\ \text{of}\ 1{,}237\ \text{calves} = 141.51$$

$$141.51 + 59 = 200.51\ \text{samples}$$

Therefore, 201 random samples of HAB cuts would need to be sampled in order to identify a non-program sample with this level of confidence (95%).

The minimum number of samples needed increases dramatically as the required level of confidence increases. In order to identify one non-program beef cut if 99 percent of the beef is from calves within the program 459 samples of beef cuts would be required. The power calculation is shown below.

$$0.99 = 1 - (1\text{-}0.01)^{x}$$

$$x = \log(1-(1-0.01))/\log(0.99)$$

$$x = 459 \text{ samples}$$

$$11.44\ \%\text{ of } 1{,}237 \text{ calves} = 141.51$$

$$141.51 + 459 = 600.51 \text{ samples}$$

The minimum number of cut beef DNA samples required given the 11.44 percent failure rate in acquiring genotypes for calves sampled within this demonstration, would be 601 samples.

3.5.6 Errors

On average, only 36 percent of the calves sampled were assigned a sire. There were two contributing factors determined for the low percentage of sire assignments made during the demonstration of this DNA tracking system.

1. Incomplete DNA representation of bull batteries

It is important to note that all the producers participating in the demonstration of this DNA tracking system were unable to provide DNA samples for all the possible sires of the calves that were included in the demonstration.

2. Highly related bulls

Canadian commercial producers are typically repeat customers once they have established a relationship with a seed stock breeder and had success with some of the breeder's bulls. This repeated purchasing behaviour can result in higher degrees of relatedness between the sires. Related bulls with highly similar genotypes make it difficult to identify the correct sire for calves from multisire pastures.

3.6 Discussion

Seed stock breeders already house pedigree, performance and SNP parentage verification genotypes in the CAA database. When Canadian Angus breeding bulls are purchased from CAA members the transfer of ownership to the commercial producer is recorded.

Subsequently, commercial producers purchase CAA RFID tags for their minimum 50 percent Angus feeder calves. Calf records are created based on the CAA RFID number. At this point, dates of birth are attributed to calf records in order to age-verify the calves with CCIA. Age verification is mandatory in several provinces within Canada, and the first product differentiation opportunity within the production chain. Using this already established database as a springboard for the DNA tracking system was a logical approach. System design extended feeder calf records to include a SNP parentage verification genotype, a specific sire, dam information where available, feedlot growth information, and carcass quality data for each feeder calf.

As per the objectives set out for this project in Section 3.2 the design and demonstration of a DNA tracking system accomplished the goal to leverage the CAA parentage verification genotype database and high throughput SNP DNA analysis technology to identify sires for feeder calves from multisire pastures. Through the project this linkage was used to deliver feeder calf performance information to seed stock breeders and commercial producers in the form of Sire Production Summaries for effective genetic selection. The demonstration allowed for the assessment of DNA sampling and genotyping technology that is both cost effective and practical at the farm, feedlot, packing plant and laboratory to ensure adoption and continued usage in the Canadian beef industry. And, the project used high throughput DNA technology to link branded beef product to the calf it came from thereby verifying the label and product differentiation. The error rates established during the demonstration allowed for the calculation of a minimum sampling threshold to ensure affordability of the label verification portion of the system.

Demonstration of the DNA tracking system began in May 2012 and was completed in October 2013. An objective of the demonstration was to assess DNA sampling technologies in various industry environments and recommend the most practical and cost effective options. Producer environments, including available labour and animal constraint appliances (such as chutes and head gates) differ greatly therefore there is merit in being able to offer producers access to various forms of technology and sampling methods that have been proven within the system. Impractical technology, especially if there is a high cost associated with it, has historically been a barrier for adoption in the Canadian beef industry. For example, DNA sampling using nasal swab technology is available but not extensively adopted because it is not very practical to approach a bull head-on to collect the sample, and bacterial contamination from the nostril greatly impacts the rate of successful DNA extraction and genotyping from the sample collected.

The producers that participated in the demonstration all preferred to pull hair samples on their animals. This methodology for DNA sampling animals is the most practical and cost effective option evaluated. DNA sampling live animals by pulling tail switch hair is relatively uncomplicated, and a process that producers are familiar with. However, the process entails wrapping the hair around a finger or a pair of pliers and sharply tugging the hair to ensure hair root attachment. These hairs must then be placed in a well labelled envelope or ‘ziplock’ bag. There is a possibility of contaminating the next hair sample collected if there is still hair attached to the fingers or the pliers. Caution must also be taken not to break the hair off, the hair root must be captured in order to collect DNA from the animal.

The applicators for both the tissue collection systems assessed include disposable punches that help avoid contamination of subsequent samples taken. However, these two sampling systems do require a head gate or chute, which not all producers have. The applicators ($35 - 60/each) and each Allflex NextGen TSU or Typifix tag are significantly more expensive than envelopes or ‘ziplock’ bags. Hair samples, in clean well labelled envelopes or ‘ziplock’ bags, can be stored indefinitely, and can be mailed with ease. Both the tissue collection devices have a preservative, the Allflex system a liquid one and the Typifix a desiccant that allows for storage of samples at room temperature for up to 2 years.

Three Typifix tags that were used to DNA sample live feeder calves at the feedlot were found to be empty at the laboratory. When sampling calves, specifically British breeds which are typically hairier around the ears, it is necessary to ensure the applicator is positioned well within the surface of the ear in order to capture a tissue sample. The Typifix tag is yellow and opaque which makes it difficult to confirm capture of sample. In comparison, the Allflex NextGen TSU is clear which made it easy to verify that a tissue sample was successfully captured. Another identified limitation of using the tissue sampling technology is that only one tissue sample is captured. The implication of this is that if a sample is accidently lost or the DNA extraction is unsuccessful for any reason, there is no opportunity to go back to the sample. Typically, enough hair is captured to allow for 3 - 5 DNA extractions. These findings were communicated to Allflex Canada and the distributor for the Typifix tags. As a result, Typifix is exploring a double punch system to capture two tissue samples. In addition, Allflex Canada has reformulated the preservative used in their TSU's to increase the rate of successful DNA extraction from tissue samples collected using their technology.

At the packing plant the IdentiGEN meat scraper was the most expensive DNA sampling device assessed within the demonstration. However, it was significantly more practical and time sensitive than using tongue depressors or plastic knives isolated in 'ziplock' bags. There may be an opportunity for improvements here, especially in terms of cost. High enrolment in the system could potentially contribute by enabling volume discounts.

At the laboratory, the novel NGG technology provided by Eureka Genomics was assessed and validated by running 192 samples in parallel using Sequenom technology and 96 samples using the Illumina HiScan machine. The technology performed very well. The results were accurate, complete genotypes for all 105 SNPs were produced, and the technology is highly cost efficient (see Table 10). This demonstration was a valuable opportunity to assess the NGG technology. It has the capacity to run a large volume of samples, conversely, the minimum number of samples required is 1000. This can be a benefit or a challenge depending on the extent of adoption of the system. The Sequenom technology requires more time to process less samples at a higher cost per sample, but would be a good back up in case a smaller set of samples needed to be genotyped.

The goal of the project was to recommend the best technology to deliver the objectives of this system. The Sequenom and Eureka genotyping technologies are both competitive in pricing and turnaround time in comparison to microsatellite technology (Allen *et al.*, 2010). The BovineSNP50 marker panel using the Illumina genotyping platform was not competitive in regards to the requirements of this DNA tracking system. The sample number processing capacity using this technology is limited. Also, the technology might seem cost prohibitive in comparison; however, the number of SNPs run on this technology was 50,000 rather than 105. This higher density genotype can be of value in the future, however, this was not the most practical technology for this system. In contrast, the NGG technology, although in its infancy, has the ability to be extremely cost effective at high volumes. Upon feedback from this demonstration Eureka Genomics is pursuing avenues by which to decrease the 8 day processing time currently required by the NGG technology.

Typically, in cases where DNA samples for the entire bull battery are available Delta Genomics reports over 99 percent sire-calf qualifications. These are improved even more if DNA samples on dams are available. As indicated, the results obtained in the project were relatively disappointing. This needs to be explained carefully and used to encourage seed stock breeders and commercial producers to DNA sample their sires prior to selling them. Although this will occur again, it is anticipated that, with effective communication, the occurrence of genotype libraries on partial bull batteries will be minimal. Hence, the proportion of calves sire verified through this system should increase dramatically.

A solution that would address both the challenges identified would be to include dam genotypes in the system. Dam genotypes should allow for more sire verifications at increased levels of confidence. Dam genotypes should help identify the correct sire in cases where more than one bull qualifies to be the sire of a calf. It should be noted that the effectiveness of genetic selection based on this DNA tracking system would be increased with the generation of Dam Production Summaries where dam information is included. This is discussed further in Chapter 4.

Sire attribution of all, or a higher percent of, the calves sampled and measured for performance at the feedlot and packing plant will certainly enable faster gains in genetic improvement at the producer level. However, there is still considerable value in the Sire Production Summaries generated for the participating producers within this demonstration. As illustrated in Figure 12 using the Sire Production Summary the producer is able to identify that bull LCE 10T threw 30 calves that were fed for slaughter. Of these, 25 were male and averaged 1244.9 lb upon arrival at the packing plant. The steers from this bull averaged 730 lb hot and 715.6 lb cold carcass weight, the average lean meat yield was 58.66 or yield grade 2. On average the 25 calves graded triple A (AAA) for marbling. These steers were on feed for 168 days and gained an average of 2.82 pounds a day. His daughters averaged 1302.1 lb upon arrival at the packing plant, averaged 765.1 lb hot and 750.8 lb cold carcass weight, averaged 58.71 lean meat yield or 2 yield grade and triple A (AAA) grade for marbling. These heifers were on feed for 190 days and gained 2.72 pounds per day. LCE 10T threw the industry average number of calves a bull would produce in a season, and his calves, on average, performed very well for the natural no added hormones, no growth promotants, no antibiotic regime of the Heritage Angus Beef program. From the Sire Production Summary the producer can also ascertain that sire LCE 41W only threw 2 calves that were placed into the program. Although not statistically significant, these 2 steer calves performed poorly for all traits recorded compared to the 25 steers from LCE 10T. LCE 41W's calves weighed on average 58.8 lb less upon entry at the packing plant, had 17.2 lb less hot and 18.1 lb less cold carcass weight, the two calves averaged 1.45 percent less lean meat yield, they both maintained a yield grade of 2 and a marbling grade of triple A (AAA). These two steers were on feed for 8 days longer and gained 0.27 lb a day less than the steers from LCE 10T.

In this instance, the valuable information is the number of calves sired. The Sire Production Summary is an example of a producer's opportunity to improve operational efficiencies by addressing the inefficiency of housing a bull that only sired two calves. There may be an environmental reason for this bull's limited fertility, or it may be his genetic potential. Fertility in cattle is lowly heritable and not easily measured, therefore tools to drive genetic improvement in fertility are of significant value to the industry (Garrick, 2011).

Additional opportunities for efficiencies to be gained from the information included on the Sire Production Summaries include days on feed at the feedlot. Feedlots endeavour to feed cattle to finish in the shortest amount of time possible to increase their own efficiencies and profit margins. The two calves from LCE 41W were on feed for 8 days longer than the average steer calf from LCE 10T. The Government of Alberta has launched an environmental protection protocol in the Canadian beef industry that encourages reducing animal age at harvest as a tool to reduce greenhouse gas emissions (Boyd *et al.*, 2012). Improvement on this one trait would benefit every sector of the Canadian beef industry:

1. The seed stock sector would benefit from increased market share given improved growth genetics.
2. Commercial producers would be able to sell their calves faster freeing up resources and feed.

3. Feedlots would reduce feed costs and could increase feedlot capacity if the calves finished to optimum slaughter weight faster.
4. Packing plants and retailers would maintain profits based on pounds of lean meat yield and stand to increase profit share from calves with added growth potential.
5. The Canadian beef industry would decrease its environmental footprint protecting environmental resources and gaining market share for the attribute.
In addition, the packing plant aims for higher yielding cattle that have less fat to trim. Trimming fat is labour and time intensive, and there is little value in the pounds of fat (Rolf *et al.*, 2011). As a result of the information gained during the demonstration of this DNA tracking system Shoestring Ranch might consider culling LCE 41W, and perhaps sourcing more bulls from the same pedigree as LCE 10T.

Information delivered via Sire Production Summaries also gives producers the opportunity to select bulls based on the carcass quality of their calves. Estimations for heritability of carcass traits range from 0.27 to 0.45 implying that selection pressure on these traits can result in significant phenotypic changes (Wilson *et al.*, 1993). Canadian beef cattle with improved genetic potential to develop better carcass quality would benefit the feedlot (which gets paid based on yield and marbling grade), the packing plant and retailer (who also garner premiums based on quality). Commercial producers who retain ownership of their feeder calves and market their product under branded beef programs, such as HAB, would also collect premiums from increased quality. In addition, most branded beef programs pay premiums for verified source information as it must meet the program's quality requirements. Improved consistent carcass quality will also guarantee a sustainable market as consumer experiences will remain positive and increase the demand for Canadian beef (Grunert, 2006).

The potential benefits of participating in this DNA tracking system and achieving genetic improvement for growth and carcass quality are clear. Every sector of the Canadian beef supply chain from the seed stock breeder to the consumer stands to benefit. The DNA tracking system has the capacity to expand and incorporate more traits of economical value in the future addressing the opportunity identified by Garrick (2011) to achieve balanced improvement across the spectrum of traits that contribute to a successful beef industry.

Despite the obvious benefit, historically there has been resistance to adoption of similar systems. Practicality and affordability are two potential barriers that are explored in more depth below. Other barriers might have included lack of leadership and trust within the industry, as discussed in the section 2.1.3 (CAPI, 2012).

Canadian traceability expert Brian Sterling and value chain leader Martin Gooch authored a report commissioned by the Agricultural Adaptation Council (AAC) and AAFC entitled Traceability is Free: Competitive Advantages of Food Traceability to Value Chain Management. The report argues that all sectors of the Canadian beef industry, starting at the producer level need to work together to guard against food related scandals such as the horse meat crisis in Europe, food safety issues and efficiency in production issues (Gooch and Sterling, 2013). The authors identify that effective livestock traceability can be an outcome of disciplined, professionally managed data gathering and analysis and collaboration.

Delivery of an audit system and label verification capabilities can also increase the value gained through this system and help the Canadian beef industry establish a more competitive place in niche markets that are demanding higher levels of traceability. The demonstration allowed for the estimation of the failure rate in the system (i.e. failure to acquire a genotype on any given sample). This was then incorporated into a power calculation that established that in a program where 95 percent of the cut beef is from 1,237 calves registered within the program 201 random cut beef samples should identify a non program carcass, if there is one. A minimum sampling threshold, established using error rates obtained from the demonstration, may provide the Canadian beef industry with the opportunity to verify branded beef product at an economically feasible rate.

The demonstration of this system shows that high throughput DNA technology can be leveraged to shift selection focus to selection of more balanced traits for increased benefits throughout the value chain. This system should facilitate the inclusion of more progeny performance data into the calculation of selection tools so that the industry can make more accurate selection decisions. Although the DNA tracking system designed and demonstrated during this project brought value to the participating producers several opportunities for future efforts were identified and are discussed in the next chapter.

Chapter 4: Future Efforts

It was hypothesized that the DNA tracking system designed and demonstrated within this project will facilitate vertical linkage within the Canadian beef industry. With a system that delivered feeder calf performance information linked to their appropriate sires to commercial producers for use towards genetic improvement. The system also provides a tool for auditing branded beef programs and verifying the labeled product. However there are several opportunities that might increase the value of this system to the Canadian beef industry.

Several of the producers that participated in the demonstration of this DNA tracking system expressed interest in receiving information back on other economically relevant traits. One of these traits is feed efficiency. A standardized approach to enable selection for improved feed efficiency has yet to be adopted by the beef industry (Miller, 2010). The primary limitation has been the inability of the industry to capture sufficient numbers of phenotypes to facilitate effective selection on large numbers of animals. However, considering that feed is estimated to comprise over 60 percent of the production cost in calf feeding systems and over 70 percent in finishing systems improvement for feed efficiency would have significant impact on the industry (Rolf *et al.*, 2012). Several Canadian feedlots are equipped with GrowSafe technology. GrowSafe Beef™ monitors feed intake for individual beef cattle based on a gated trough with an RFID scanner at the entrance. The scanner reads the RFID number of the animal as its head enters the trough. The scale under the trough records the daily dry matter intake for the animal. This information coupled with animal growth and body condition information allows for an estimation of residual feed intake (RFI). The addition of RFI information to this DNA tracking system will have significant potential benefit to the Canadian beef industry in its challenge to produce beef more efficiently using fewer resources. Improvement in feed efficiency would also result in the industry leaving a lighter footprint on the environment. Genetic selection for residual feed intake is an indirect approach for reducing enteric methane (CH_4) emissions in beef and dairy cattle (Basarab *et al.*, 2013). Selecting on traits that improve the efficiency of the system (e.g. residual feed intake, longevity) will have a favourable effect on the overall emissions from the system (Wall, Bell and Simm, 2008).

Another opportunity for expansion of traits recorded within this DNA tracking system is feedlot health. Records of calf treatment, morbidity and mortality are already kept at most feedlots across the country. Like other information in the segmented Canadian beef industry structure the information is not typically applied towards genetic improvement. Health and immune response are otherwise difficult and expensive traits to measure. However, the potential opportunity to link feeder calf feedlot health records to their sire genetics might led the Canadian beef industry to great sustainability through efficiencies, minimized calf loss, and less use of antibiotics. This DNA tracking system was designed with the flexibility to incorporate any production trait that the Canadian beef industry might identify as economically beneficial to improve upon in the future.

In addition to recording new traits, this system can also be tied into the Canadian Angus Performance Program through which EPDs for registered seed stock Angus are calculated. The Performance Program currently only uses ultrasound scanning information and genomic markers associated with variation in carcass quality as indicator traits with which to calculate Carcass EPDs. Actual carcass quality information from the kill floor has to date never been available for verified progeny of registered Canadian Angus bulls. Incorporation of feeder calf carcass quality information would enable more accurate predictions of genetic merit for registered seed stock. In turn, this would allow producers to select better genetics at time of purchase. Similarly, progeny performance for other traits like residual feed intake recorded in this DNA tracking system may be incorporated in the calculation of EPDs for registered seed stock cattle in the Performance Program.

Another potential future endeavour identified as an opportunity to improve this DNA tracking system is to use higher density SNP panels with which to make parentage calls. ISAG recommends an extra 100 SNPs in cases where there are more than one qualified sire (ISAG, 2012). A higher number of SNPs would allow for greater distinction between related sires and potentially decrease the number of calves with more than one qualified sire. The opportunity to sire verify a higher proportion of calves in the system would need to be balanced with the increased cost of extended genotyping. Further, several producers within this demonstration showed an interest to include dam information into the system in order to address both opportunities for genetic improvement. Dam genotypes would also increase the confidence level of parentage verification calls made as both genotypes for each DNA locus would be identified. New technology such as NGG (Eureka Genomics) may assist here, especially as there may be relatively large volumes of DNA samples to genotype if dams are included.

Lastly, this DNA tracking system was designed and demonstrated with an already integrated supply chain in that Heritage Angus Beef producers retain ownership of their calves and market their own branded beef product, and therefore get paid based on the end retail product rather than by the pound of weaned calf. For higher levels of adoption in the Canadian beef industry this DNA tracking system must also bring value to producers who sell their feeder calves in cash markets. This system is designed to receive data from individual sectors of the industry, however, unless those sectors are submitting downstream information on the same calves that are being recorded upstream the full value of the system will not be realized. Therefore, a future endeavour for this system may be to create alliances with branded beef programs encouraging participation in the system along the chain via a pull market downstream. The Canadian Angus Association has pre-established relationships with producers who run branded beef programs that source feeder calves from cash markets under the Canadian Angus Rancher Endorsed program. These alliances might be leveraged to help integrate this DNA tracking system in the industry where producers do not retain ownership of their calves.

Future efforts to improve upon the value delivered through this system will focus on delivering tools that help the Canadian beef industry meet the challenges of increased competition for natural resources, global climate change, and competition from other protein sources. Future system enhancements will be made with the aim to elevate the industry's ability to maximize the opportunity of a growing world population, specifically a growing affluent middle class. The objective of facilitating more accurate identification of superior breeding animals for genetic improvement will continue to be a primary focus for the CAA which will continue to grow its genetic evaluations and Ranchers Endorsed branded beef program alliances.

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