The Role of Animal Genomics in Reducing Greenhouse Gas Emissions

Paper prepared for CAPI

by

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September 2018

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Introduction

A primary goal for producers and policymakers is to enhance the competitiveness of the Canadian livestock industry while simultaneously mitigating greenhouse gases (GHG) and adapting to the effects of climate change. Global consumption of animal protein is forecasted to increase significantly in the next three decades (FAO, 2011; Tilman and Clark, 2014; McAlpine et al., 2009). This increased demand will be driven by population growth, an expanding middle class, urbanization and changes in dietary preferences (FAO, 2012). Increases in productivity will allow livestock industries to meet this increased demand but maintaining environmental sustainability presents a further challenge. Environmental sustainability requires both that livestock industries improve their resilience to a changing climate and that their own environmental impact is mitigated. Recently, a novel advancement in genomics has made it possible to selectively breed animals for increases in feed efficiency, which also holds promise in reducing GHG emissions (Chesnais et al., 2016; de Haas et al., 2011; Bell et al., 2011). Improving feed efficiency through genomic technologies can simultaneously boost industry competitiveness by lowering input costs and enhance environmental sustainability.

The scientific literature suggests that feed intake and methane emissions are positively correlated as animals that eat more also tend to emit more (Knapp et al., 2014; de Haas et al., 2011). Higher feed intakes also lead to higher costs and feed is often the highest variable cost of meat, milk and other animal protein production (Dilenzo and Lamb, 2012). The introduction of genomic technologies may offer a win-win outcome for producers and the environment/society, and the Canadian livestock industry may be particularly well placed to take advantage of this opportunity for two reasons. First, increasing the competitiveness of the Canadian livestock sector is a popular area of research/concern for agricultural economists and policymakers as the sector continues to face increasing international competition. One area in which Canadian dairy, for example, may have a significant advantage is in biotechnologies such as genomics (AAFC, 2016). Advances in genomic selection for reductions in GHG emissions may provide a better position of competitiveness relative to other countries' livestock sectors. Second, with recent policy initiatives from the federal government on the topic of pricing emissions, it may be beneficial for livestock producers to proactively adopt technologies that both increase their profits while reducing their environmental footprint.

Concerns about increased animal protein demand and its associated global environmental impact have spurred several countries into developing and implementing innovative technologies and best management practices. For example, in dairy production, the use of higher corn silage ratios in forages and increased fat content in diets are both implemented currently and can reduce methane emissions from the herd (Jayasundara et al., 2016). However, discovering new technologies or management practices that benefit producers and greater society alike as well as seeing widespread adoption are less common. Genomic selection for feed efficiency may be able to offer this win-win outcome while also being used in combination with other established technologies and practices. Specifically, the use of genomic information in breeding will provide producers with information about feed efficiency and methane emissions as well as a wide range of other traits (e.g., yield, fertility, health, duration, resiliency) that will assist producers in making informed livestock production and management decisions.

Objective

In this paper, I review the potential of genomics to increase feed efficiency and reduce the environmental footprint of the livestock sector as well as improving the competitiveness and productivity of the industry.

The Issue: Greenhouse Gas Emissions from Livestock

The contribution of livestock production to greenhouse gas emissions and climate change has attracted attention from popular media (mainstream and social), politicians, academics, and businesses. For example, Alberta recognizes the importance of reducing the amount of greenhouse gases produced by the livestock sector and introduced the Alberta Offset System. As an example of social media, a February 2013 TED Talk presented by Allan Savory proposes a holistic system or a short duration grazing to restore degraded deserts and grasslands and reverse climate change. Meanwhile, the Institute for Agriculture and Trade Policy (IATP) and the international nonprofit GRAIN report that the combined supply chain emissions from the top five largest dairy and meat processors (i.e., Brazil's JBS, New Zealand's Fonterra, Dairy Farmers of America, Tyson Foods, and Cargill, 578.3 Mt) is higher than Exxon-Mobil (577 Mt), Shell (508 Mt), or BP (448 Mt). The report concludes that "…we must reduce production and consumption of meat and dairy in overproducing and overconsuming countries and in affluent populations globally…." (GRAIN and IATP 2018; p. 2).

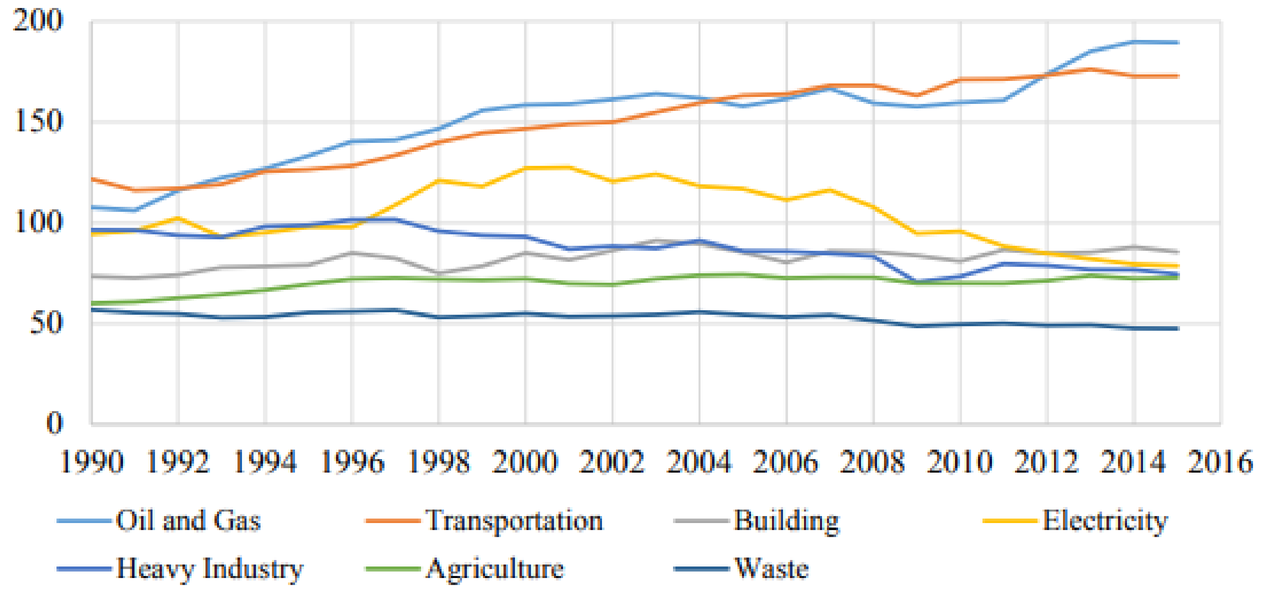
According to Environment Canada and Climate Change (2017), Canada's total greenhouse gas emissions for 2015 was 722 megatonnes (Mt)[1] of carbon dioxide equivalent (CO_2-eq) (Figure 1). The oil and gas sector was the largest source of GHG emissions and accounts for 26% of Canada's total emissions. In the same year, the agriculture sector accounted for approximately 10% (72.8 Mt CO_2-eq) of total national emissions. Since 1990, there has been an increase in agricultural GHG emissions by approximately 20% (Figure 1). Meanwhile, the GRAIN and IATP report show that the Canadian meat and dairy supply chain[2] alone emitted 72.6 Mt CO_2-eq in 2017.

For the agriculture sector, emissions from enteric fermentation accounted for 40.7% (24 Mt CO_2-eq), manure management for 13.6% (8 Mt CO_2-eq), agricultural soils for 39% (23 Mt CO_2-eq), and liming, urea application and other carbon-containing fertilizers accounted for 5.1% (3 Mt CO_2- eq) of the total 72.8 Mt CO_2-eq emissions from the agriculture sector (Figure 2). Globally, livestock contributes to between 18% and 51% of the anthropogenic greenhouse gas emissions (De Schutter, 2014). De Schutter (2014, p. 6) note that a "25 per cent reduction in livestock products worldwide between 2009 and 2017 could result in a 12.5 per cent reduction in global atmospheric greenhouse gas emissions." Yet, as trends indicate an increase in the global demand for livestock products, it is likely that more efficient and environmentally friendly means of production will need to be implemented for demand to be met sustainably.

1 Note that 1 Megatonne (Mt) = 1,000,000 metric tons = 1,000,000,000 kg.

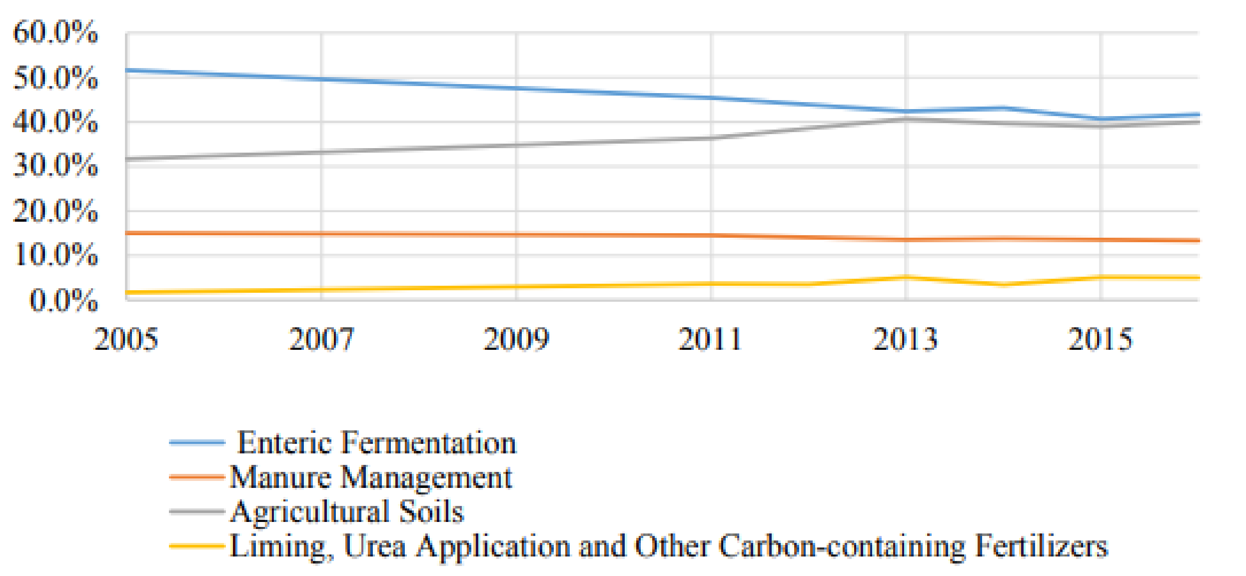
2 Supply chain emissions accounts for upstream and downstream emissions "… covering everything from the production of animal feed crops to the methane released by cattle..." (GRAIN and IATP 2018; p. 6).

Figure 1. Greenhouse Gas Emissions By Canadian Economic Sector in Megatonnes (Mt) of Carbon Dioxide Equivalent (CO_2-eq) - 1990 to 2015



Source: Environment Canada and Climate Change, 2017.

Figure 2. Canada's Agriculture Greenhouse Gas Emissions By Intergovernmental Panel on Climate Change Sector, (%)



Source: Environment Canada and Climate Change, 2017

Methane (CH_4) is the main greenhouse gas emitted by livestock. According to AAFC, beef and dairy are the major contributors – 88% – to methane emissions (Agriculture and Agri-Food Canada, 2017). Within the beef supply chain, Beauchemin et al. (2011) note that the cow-calf operations contribute to 80% of GHG emissions and feedlot operations to 20%. The importance of understanding the various stages of the supply chain and the role that it plays in the adoption of genomic selection for feed efficiency and reduced methane emissions is discussed further on in this document.

The Responses: Market, Policy, Management Practices and Greenhouse Gas Emissions

Various mechanisms have been used to reduce the environmental footprint of livestock production. Among others, standards and regulations and market-based instruments (MBIs) have been used worldwide in livestock production to address environmentally detrimental nutrient levels. Standards are the most common forms of environmental policies. Standards set maximum permitted levels of emissions or nutrient pollution. Examples of these instruments can be found in Europe (e.g., EU Nitrate Directive), the United States (e.g., Clean Water Act, Nutrient Management Act), New Zealand (e.g., Resource Management Act), and Canada (e.g., Nutrient Management Act). Regulations are generally avoided by policymakers because of their inherently high cost and inefficiency relative to market mechanisms.

An alternative to standards or regulations is market-based instruments that use price and other economic mechanisms to provide incentives (e.g., taxes, subsidies and tradable permits, carbon credit markets) for producers to reduce emissions or nutrient pollution. Economists generally prescribe carbon pricing as the most efficient market mechanism to mitigate greenhouse gas emissions. If the negative externalities caused by the production of a commodity is not reflected in the price of the commodity, social welfare can be improved by imposing a tax. In October 2016, the Government of Canada announced its commitment to carbon (pollution) pricing through the Pan-Canadian approach. Slade (2018), for example, shows that a farm level carbon tax (subsidy) for livestock producers creates the greatest GHG emissions reduction at a lower (higher) social cost per unit of emissions abatement than a subsidy (tax). Boaitey and Goddard (2016, p. 18) find that, given the current price of carbon and the level of emissions per farm, producers are "less likely to participate in in voluntary carbon credit scheme."

Some jurisdictions have implemented carbon offset schemes that are designed to offset or neutralize greenhouse gas emissions through investment in environmentally friendly management practices, processes and technologies. For example, Australia implemented the Australian Carbon Farming Initiative, which allows livestock producers to benefit from using GHG reducing practices (e.g., select for low residual feed intake, dietary supplements, manure management) (Australian Government, 2017). In Canada, the Alberta Offset System provides incentives for the province of Alberta beef and dairy producers if they implement certain activities (e.g., selection for low residual feed intake, reduced days on feed, manure management strategies, increased milk production). In the U.S, the Regional Greenhouse Gas Initiative provides producers with credit for reducing methane emissions from dairy cows using anaerobic digesters. In California (U.S.), as well, the Livestock Projects Compliance Offset Protocol provides incentives for using anaerobic digesters to manage manure on dairy and swine farms.

The economic literature recognizes the role that technological progress plays in enhancing agricultural productivity and sustainability (Sunding and Zilberman, 2001) and several studies have examined the participation and valuation of producers' different environmental management practices, technologies and carbon offset schemes. For example, Bosch et al. (2008) examined the effect of revenue from carbon credits on the adoption of rotational grazing practices in the cow-calf and dairy sectors. Bosch et al find that the CO_2-eq credit ranges between 76.2 and 86.8 tons per farm for cow-calf and -7.3 and 10.6 tons per farm for dairy farms. Based on a credit of $15 per ton of emissions reduction, they find that the net benefits from the sale of carbon credits may not be sufficient (and is less than $1,500 per farm under all scenarios) to provide incentives to producers to change their production and management practices. The CO_2-eq emissions reduction is mainly because of the increase in carbon soil sequestration. Because of a higher stocking rate intensity, methane emissions increase with rotational grazing, as does N_2O emissions (Bosch et al., 2008). This is, however, more than offset by the CO_2 sequestration.

Studies on anaerobic digesters show that because of the substantial initial capital investment required, to make it attractive from the environmental perspective, the price of carbon credits may need to be in the range of $20 - $30 per ton. As well, the technology is not neutral to the scale of the operation, meaning that larger scale farmers are more likely to benefit because of the economies of scale (Gloy, 2011). The size-adoption relationship may point to a need to pay careful attention to farm characteristics when designing policy or incentive schemes that are targeted at enhancing the adoption of environmental technologies.

The Opportunities: Mitigation Practices & Genomic Selection for Feed Efficiency

The scientific literature indicates that methane emissions from livestock depend on diet, genetics, the microbiology of the bovine's rumen (Tapio et al., 2017; Söllinger et al., 2018), and management practices[3]. Several studies have examined different ways of reducing on-farm methane emissions from beef and dairy cattle: Feeding practices (Jordan et al., 2006a,b,c; Beauchemin and McGinn, 2006; McGinn et al.; 2004; Lovett et al., 2003; Hawkins et al., 2015); grazing management (Stewart et al., 2009); manure management (Gloy et al., 2011; Anderson et al 2013; Anderson and Weersink, 2014); use of bovine somatotrophin (bST) and hormonal growth implants (Johnson et al., 1991); and dietary additives (McGinn, 2004). These studies show that the use of management practices may result in lower feed intake and lower methane emissions. For example, Stewart et al. (2009) find that keeping cattle on alfalfa reduces methane emissions by 0.53 to 1.08 tonnes CO_2-equivalent, whereas Gloy (2011) finds that the use of anaerobic digesters on dairy farms in the U.S. reduces methane emissions by approximately 220 tonnes per unit. A holistic management system (HM) – i.e., frequently rotating livestock herds to improve soil health – that is popularized after the February 2013 Ted Talk by Allan Savory (titled: *How to fight desertification and reverse climate change*) is another environmental management practice that is both praised and criticized. As of July 2018, the talk has been viewed 4,701,875 times, and the transcript is translated to 35 languages. Critics such as Carter et al. (2014) question the validity of the Savory's claim that global desertification can be stopped by having more livestock grazing on grasslands, prairies, deserts, and other arid and semiarid areas where the soil is vulnerable to erosion because of climate change. Carter et al. (2014) challenge the assumptions of the HM with a focus on North American arid and semiarid ecosystems and note that "… research indicates that not only does HM not produce results superior to conventional season-long grazing, but also that

[3] For research papers on international farm-level adoption of soil management and agricultural conservation practices see Knowler and Bradshaw (2007).

stocking rate, rest, and livestock exclusion represent the best mechanisms for restoring grassland productivity, ecological condition, and sustainability." (p. 7).

Breeding animals for feed efficiency (i.e., lower feed intake while holding all other traits constant) may provide another option for producers seeking to reduce their GHG emissions from cattle (Basarab et al., 2013 de Haas et al., 2011; Knapp et al., 2014). Basarab et al. (2013) indicate that genetic selection for feed efficiency provides an indirect way of reducing enteric methane (CH_4) emissions from beef and dairy cattle. According to Basarab et al., (p. 333) "Selection for residual feed intake… will result in cattle that consume less dry matter intake, have improved feed conversion ratio and reduced enteric CH_4 emissions at equal levels of production, body size and body fatness." Boaitey et al. (2017) show that, on average, a kilogram reduction in feed in take per day may increase net returns by $13.23 and reduce emission by 33.46 tonnes at the end of the feeding period.

Until recently, the Canadian livestock industry was mainly focused on improving attributes related to production such as yield, reproduction, health, longevity and their overall shape. This has led to a significant increase in productivity – for example, in the dairy industry milk yield has increased by 122.5% between 1956 and 2017; and by 10.5% between 2007 and 2017 (Canadian Dairy Information Centre, 2017). Prior to the introduction of genomic technologies, selectively breeding for feed efficiency was prohibitively expensive because tracking information for feed intakes is costly at a phenotypic level (i.e., expressed physical traits of the animal). However, over the last decade, with the introduction of genomics, there has been a determined effort to be able to select animals for feed efficiency and reduced greenhouse gas emissions as identifying and selecting for these traits at the genotypic level is relatively inexpensive (Pryce et al., 2014; Calus et al., 2015).

In the last two to three years, progress has been made in identifying the trait associated with feed efficiency and reduced methane emissions, to allow producers to actively breed for these traits. Livestock Gentec, which is based at the University of Alberta, is an example of such efforts. Livestock Gentec has more than 30 completed and on-going research projects on bovine genomics (Livestock Gentec, 2018). The strategic goal of more than three-quarters of these projects is increasing feed efficiency, and about one third of the research projects mainly focus on reducing methane/GHG emissions. The Efficient Dairy Genome Project (EDGP) is another large international research project primarily funded by Genome Canada with the objective "… to improve feed efficiency and reduce methane emissions in dairy cattle using genomics…" (The Efficient Dairy Genome Project, 2018).

Despite the increased effort in selecting animals for feed efficiency and reduced GHG emissions, we have limited information on the economic impact of adoption. Little is known in terms of how the adoption of genomic selection will impact livestock farmers, the industry and the environment, as well as the barriers to investing in genomic selection for GHG emission reductions. While some of the recent dairy science literature on feed efficiency traits has attempted to assess the value of selecting for the trait, the estimations remain limited (Pryce et al., 2015; Pryce et al., 2014).

Understanding the return on investment as well as the distribution of those returns throughout the industry and to broader society is crucial to understanding the economic viability of the technology and the likelihood of widespread adoption. First, ensuring a positive return on investment at the farm level is essential for the diffusion of the technology to occur. However, if adoption is not initially profitable there may be justification for subsidy considering the potential for positive externalities through reduced greenhouse gas emissions. Second, adoption may be profitable for some producers and not for others depending on farm characteristics (e.g., scale, location, financial structure, etc.) and their position within the supply chain (e.g., cow-calf versus feedlot producers). Third, the distribution of returns from adoption may be allocated in a variety of ways. For example, it may be that certain genomic technologies developed in Canada may benefit larger scale operations that are typically seen abroad and are therefore more economically or environmentally beneficial to other countries with larger operations. Canada is a major exporter of livestock genetics and developments in genomic technologies may have a positive spillover effect by contributing to a reduction in greenhouse gas emissions globally. For example, in 2017, Canadian producers exported nearly $149 million worth of embryos and semen for dairy production (Canadian Dairy Information Centre, 2018).

What is the Potential Impact of Improvements in Animal Genomics on GHG Emissions?

Emerging literature on the economic and environmental benefits of genomics has established that genomic selection can have substantial economic and environmental benefits (Pryce and Hayes, 2012; Yu, 2014; Hailu et al., 2016; Goddard et al., 2016; Boaitey, 2017; Worden and Hailu, 2018; Jones, 2018). Goddard et al. (2017) show that the adoption of genomic selection for feed efficiency provides positive economic benefits to beef industry and environmental benefits to society. Goddard et al. use farm-level modelling of the beef supply chain to assess the gain in net income and reduction in methane emissions. Goddard et al. indicate that the use of the technology may be hampered by the nature of the supply chain. The distribution of the benefits from the use of genomic selection may be biased towards feedlot operators, and the authors argue that the lack of a mechanism that rewards cow-calf farms for the cost of the technology may slow its adoption and diffusion (Boaitey, 2017). Kessler (2014) also notes that cow-calf producers may have little incentive to adopt if they do not anticipate a better price for the progeny of genomically selected bulls.

Hailu et al. (2016) find that dairy producers are willing to pay approximately $50 per head for genotyping animals for susceptibility to a chronic bovine mastitis trait. They also show that producers with higher risk tolerances are willing to pay more for genotyping services, and farmers with many social interactions with their peers are also willing to pay more. Worden and Hailu (2018) assess farm level economic and environmental impact of adoption of genomically selected semen and heifers in dairy production. Worden and Hailu (2018) find positive net financial benefits to producers and a reduction in methane emissions compared to non-adopters, but they note that these benefits depend on the predictive accuracy of the genomic selection.

Jones (2018) estimated the willingness to pay for feed efficiency (FE) and reduced methane emissions (RME) traits separately and jointly. Jones finds that dairy producers are willing to pay a positive premium for increased feed efficiency traits, and no premium for reduced methane emissions (RME) traits. However, she finds that when the two traits are bundled together, producers are willing to pay more than what they indicated for feed efficiency traits alone. Further, she shows that producers with higher concerns about the greenhouse gas emissions produced by their herd are willing to pay more for the genomic selection of a feed efficiency trait, reduced methane emissions trait, and both traits combined when purchasing straws of artificial insemination. Belief in genomics also generates a positive effect on the willingness to pay for the technology (Jones, 2018). In Australia, Pryce and Hayes (2012) show that for genomic selection (i.e., genotyping) to be competitive with conventional selection procedures (i.e., parent average breeding values), the prices of genotyping must be very low. In addition, reductions of over half a million tonnes of methane (over a 25-year period) were reported in a geneflow assessment of improvements in the trait in Australia (Alford et al., 2006). Similarly, de Haas et al., (2011) has suggested that selecting for feed efficiency could reduce methane emissions by up to 26% over a 10-year period. Targeting methane emissions is also desirable because it is less expensive to mitigate than carbon dioxide emissions (Knapp et al., 2014). The combination of improved competitiveness, profitability as well as increased environmental sustainability make the adoption of genomic selection for feed efficiency and reduced methane emissions a promising innovation.

The Challenges: GHG Emissions and Livestock Genetics/Genomics

While the literature acknowledges the positive outcomes from genomic selection in livestock to improve profitability and/or reduce greenhouse gas emissions, most of the studies mentioned above document potential challenges in ensuring adoption. Incentive compatibility across the supply chain is noted as a potential hurdle to adoption and illustrates the importance of understanding how benefits may be distributed across different producers within a sector (Goddard et al., 2016; Boaitey, 2017; Kessler, 2014). Risk and uncertainty are also significant challenges to overcome for producers as those with higher risk tolerances may be more willing to use genomics and uncertainty regarding the predictive accuracy of genomic information can limit expected returns (Hailu et al., 2016; Worden and Hailu, 2018). Furthermore, individual producer characteristics such as their attitudes towards genomic technologies, concern about biodiversity, knowledge of biodiversity, and their perception of their own farm's emissions can significantly alter their willingness to pay to adopt genomic selection for increased feed efficiency and reduced methane emissions (Jones, 2018; Boaitey et al., 2018).

Reducing greenhouse gas emissions in livestock production is desirable because of its benefit to society in reducing the effects of climate change. However, this societal benefit cannot be realized unless the private benefit is made apparent to producers. For adoption of genomic selection for increased feed efficiency and reduced methane emissions to become widespread, the economic benefits to producers need to be clearly established.

Summary – The Road Ahead

One of the most significant global challenges of the 21st century lies in providing enough affordable and accessible food to meet the demands of an increasing population and simultaneously improving environmental sustainability. Biotechnologies such as genomic selection for increased feed efficiency and reduced methane emissions promises to accomplish this goal in the livestock sector. To ensure this, the economic and environmental benefits will need to be clearly established and adoption will need to be widespread. In Canada, fulfilling this goal will require careful policy considerations that are well informed by the growing body of scientific research.

In this article, I reviewed the potential of genomic technology in enhancing the competitiveness and sustainability of animal protein production. The review shows that the increasing investment in genomic technologies in Canada to improve feed efficiency and reduce greenhouse gas emissions reflects the importance of the issue to the industry. The review also demonstrates that, in general, producers are more likely to adopt the technology when they see direct financial benefits. Some of the relevant policy questions that can be addressed include: whether genomic selection for a reduction in GHG emissions will likely be adopted widely by livestock producers and to what extent (only top performing farms, the majority, etc.). What barriers may stand in the way of producers adopting (e.g., access to credit, quota restrictions for dairy, cost of genomic selection/artificial insemination, private versus social benefits, supply chain incentive incompatibility for beef, the predictive accuracy of genomic information)? What role should the federal and provincial governments play in mitigating those constraints (e.g., subsidy, research funding, improved market access, establishing carbon market)? What level of reduction in GHG emissions is expected, how does it compare with that of other environmental best management practices, and how might producers alter their other environmental best management practices post-adoption? How might producers alter their cropland and feed purchasing decisions post- adoption? In these questions, there is room for policymakers involvement either in facilitating or encouraging adoption or planning/regulating for potential changes in the industry.

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