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Tackling the Farm Crisis and the Climate Crisis:

A Transformative Strategy for Canadian Farms and Food Systems

A discussion paper
by Darrin Qualman
In collaboration with the National Farmers Union

The NFU acknowledges its Farming Climate Solutions supporters and collaborators:

IVEY FOUNDATION

Prairie Climate Centre
From Risk to Resilience

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Suggested citation: Darrin Qualman and the National Farmers Union, *Tackling the Farm Crisis and the Climate Crisis: A Transformative Strategy for Canadian Farms and Food Systems*, discussion document (Saskatoon: NFU, 2019).

This report is the product of hundreds of minds and decades of thinking and learning within farm communities and within the NFU. The NFU would like to acknowledge the very important lead role taken by NFU-Manitoba (Region 5), and especially by Manitoba Board Members Ian Robson and Dean Harder. Without their work this report would not have been possible.

Lead author and researcher: Darrin Qualman (darrin@darrinqualman.com). Research assistance provided by Avery Simundsson, Jamie Labrecque, and dozens of NFU members, staff, and experts.

This report is the creation of an organization and its membership. The NFU and Darrin Qualman would like to acknowledge and thank the following people for research, information, suggestions, critiques, and other contributions:

> Manitoba: NFU members and officials Ian Robson, Lois Robson, Dean Harder, Gary Martens, Bill Paton, Annette Desmarais, Iain Aitkin, Fred Tait, Gerry Dubé, Lydia Carpenter, Ken Sigurdson, Wilfred (Butch) Harder, Frieda Krpan, Bill Uruski, and many, many others who attended meetings, asked questions, and provided ideas for this report.
>
> Saskatchewan: NFU members, officials, and staff Patty Englund, Cathy Holtslander, Margret Asmuss, Ian McCreary, Mary Smiley, Murray Hidlebaugh, Stewart Wells, Terry Toews, Nettie Wiebe, Jim Robbins, Wendy Manson, Bruce Hopkins, Terry Boehm, Glenn Wright, and Cam Goff.
>
> Alberta: NFU members and officials Toby Malloy, Blake Hall, Ken Larsen, and Cory Ollikka.
>
> Ontario: NFU members and officials Katie Ward and Rick Munroe.
>
> Quebec: NFU members and officials Stuart Oke and Paul Slomp.
>
> Nova Scotia: NFU members and officials Jessie MacInnis.
>
> British Columbia: NFU member and officials Jan Slomp.

Though the preceding people contributed invaluable assistance in understanding agriculture and climate change, the opinions in this report do not always reflect their views.

Our organization is grateful to a number of experts and scientists who took the time to meet with our researchers and share information about their work on agriculture, soils, livestock, emissions, and climate. The NFU was fortunate to meet with experts, scientists, and academics at the University of Manitoba, including Dr. Karin Wittenberg, Dr. Kim Ominski, Dr. Mario Tenuta, and Dr. Brian Amiro; at the University of Winnipeg, Dr. Danny Blair, and Dr. Ian Mauro; and at Agriculture and Agri-Food Canada's Brandon Research Centre Dr. Allan Moulin and Dr. Aaron Glenn. The NFU also benefited from the rich resource of publicly funded science from Canadian researchers published in peer-reviewed science journals.

Canada's NFU is a direct-membership, national organization. Founded in 1969, and with roots going back more than a century, the NFU represents thousands of farm families from coast to coast, and also enjoys the support of many non-farmer Associate Members. The NFU embodies the principle that all farmers share common problems and that farm families must come together, and work with our non-farmers allies, in order to address those problems. The NFU works toward the development of economic and social policies that will maintain the family farm as the primary unit of food production in Canada, and that will give farmers effective, collective power in a marketplace dominated by agribusiness giants. Our organization believes that agriculture should be economically, socially, and environmentally sustainable. Food production should lead to enriched soils, a more beautiful countryside, jobs for non-farmers, thriving rural communities, and healthy natural ecosystems.

The NFU's membership and governance structures are democratic, participatory, and progressive. A family farm membership gives equal participation rights to all family members over the age of 14. The NFU has leadership positions for youth, women, and men. It was the first major farm organization in Canada to elect a woman as President.

To learn more about the NFU, please go to our website: www.nfu.ca. **Please join the NFU, as a farm family, a farm youth member, or a non-farmer Associate Member**. The NFU has worked tirelessly for five decades to help citizens and farmers navigate a path to a better, more sustainable, more just, and more delicious food system.

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Foreword

Farmers must act quickly, ambitiously, and collectively to advance solutions.
The alternative is to surrender leadership and control to others.

The farm crisis is real, as is the climate crisis. Left unchecked, the climate crisis will dramatically deepen the income crisis on Canada's farms as farmers struggle to deal with continued warming, more intense storms, and increasingly unpredictable weather. It is clear that climate change represents a major challenge to agriculture, but it also represents an opportunity.

Based on extensive research, this report argues that the very factors driving the climate crisis are also driving the farm crisis. It also presents opportunities for reducing greenhouse gas emissions from agriculture that will also strengthen the family farm.

This report does not claim to have all the answers. Both the climate crisis and the farm crisis are so complex that no single report can provide all the answers. This report, however, does have many answers—some of which could be implemented right away. Others provide a starting point to opening up the climate conversation in the agricultural sector. Options that will work for different geographic locations, soil types, or types of farms will be explored, but there is no one-size-fits-all solution.

Farmers and policymakers are encouraged to recognize that we are facing an existential crisis, which means that all of our options must be on the table for consideration, even if they are uncomfortable to consider. If we commit to an open and honest conversation about the causes and effects of climate change and how they are intertwined with our agricultural sector, we also take the first steps towards a transition that will benefit us all. Accordingly, by publishing this report we signal our commitment to participating in a meaningful conversation among farmers, scientists and policymakers that will evolve as our understanding and knowledge increases.

Farmers provide the food we all depend upon. Our ability to continue to do this is threatened by the intertwined crises of climate and agriculture. With this report we invite you to join us in navigating a shared journey towards a sustainable future.

Katie Ward
NFU National President

Introduction and Executive Summary

The farm crisis and the climate crisis share many of the same causes, and many of the same solutions.

The climate crisis

6.4 degrees Celsius. That's the amount of warming that may ravage many areas of Canada this century. Unless we do something. This report outlines how farm families can contribute to doing something.

The climate crisis is real, unfolding rapidly, causing destruction, and accelerating. If we do not change course its effects will be devastating. Unless Canada and all other nations act rapidly to reduce emissions—to restructure our energy, manufacturing, transportation, communication, and *food* systems—we will drive temperatures upward so far, and destabilize the climate so much, that our societies and ecosystems will be massively damaged. Unless we act now to slash emissions, we will trigger or intensify droughts and famines, mass migrations, sea level rise that will submerge some island nations, economic decline or collapse, the loss of much of the planet's rainforests and coral reefs, desertification, feedbacks that further accelerate warming, and the most rapid extinction event in 65 million years.[1]

Closer to home, farming and food production in many areas of Canada will be severely affected, negatively impacting the entire Canadian economy. This and more will transpire if we continue down the current path.

The farm crisis

In addition to a climate crisis, we also have a farm crisis. Canadian farm debt has nearly doubled since 2000 and now stands at a record $106 billion. Over the last three decades, the agribusiness corporations that supply fertilizers, chemicals, machinery, fuels, technologies, services, credit, and other materials and services have captured 95% of all farm revenues, leaving farmers just 5%. Even during the relatively good times since 2007, the majority of farm family household income has had to come from off-farm work, taxpayer-funded support programs, and other non-farm sources.

High input costs, low margins and net incomes, and expensive land and machinery have led to an expulsion of farm families from the land, with one-third leaving in just the past generation. Worse still, young farmers—those under the age of 35—are being forced out at twice the rate of farmers overall; Canada has lost more than two-thirds of its young farmers since 1991. Unless Canadian agricultural policies are wholly restructured there may be just 100,000 farms left by mid-century and the sector may come to be dominated by huge operations. Family farms are being systematically destroyed by dysfunctional, extractive, agribusiness-controlled markets and ill-conceived and damaging government policies.

The climate crisis *and* the farm crisis

The preceding paragraphs paint a bleak picture—a grim future. But these worst-case scenarios *do not have to come to pass*. They will come to pass if farmers, other citizens, and our elected leaders do not act. *But we have alternatives*. There is time and there is good news. We can change course, restructure and

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[1] That extinction event has already begun and will be accelerated by climate change. See, for instance, G. Ceballos et al., "Accelerated Modern Human-Induced Species Losses: Entering the Sixth Mass Extinction," *Science Advances* 1, no. 5 (2015).

redirect, and move toward solutions. We can build a future that includes family farms, vibrant communities, and a habitable climate. And, for farmers and all Canadians who care about our food system, movement toward a better future begins with a key insight: ***the farm crisis and the climate crisis share many of the same causes, and many of the same solutions*.**

At the core of agricultural policies in Canada and many other nations is a focus on maximizing agri-food production and exports. But maximizing agricultural outputs has also led us to maximize agricultural *inputs*. Canadian farmers have tripled nitrogen fertilizer use since 1980. They have doubled or tripled pesticide use since 1990. Farmers have been pushed to adopt a maximum-output, maximum-input production approach. The result, however, is that over the past generation input suppliers have captured 95 cents out of every dollar farmers received from the markets. Fertilizer, chemical, fuel, machinery companies and banks have installed themselves as the primary beneficiaries of Canadian agricultural wealth creation. This unrelenting and aggressive wealth extraction threatens to drain and collapse the family farm sector by mid-century.

So, where's the good news? It begins with the knowledge that a focus on high-output, high-input agriculture is the primary cause of the farm crisis *and the primary cause of the increasing greenhouse gas (GHG) emissions from our farms and food-production systems*. It begins with the realization that as we reduce farm input use we can increase net farm income *and* reduce GHG emissions. Here is a provocative idea: farming does not produce greenhouse gas emissions; *agricultural inputs* produce greenhouse gas emissions. The emissions coming out of our farm and food systems are simply the downstream outputs of the petro-industrial inputs we push in. Push in millions of gallons of fossil fuels and they will come out as millions of tonnes of carbon dioxide. Push in megatonnes of fertilizers and they will come out as megatonnes of nitrous oxide. As we have doubled and redoubled input use, we have doubled and redoubled the GHG emissions from agriculture.

The seemingly inescapable conclusion is this: *any low-emission food-production system will be a low-input food production system*. And as we change policies and approaches to reduce and optimize input use, farm incomes can rise. The solution to the farm crisis and the solution to the climate crisis are, to a large degree, the same: a decreased dependence on high-emission petro-industrial farm inputs and an increasing reliance on ecological cycles, biology, energy from the sun, and the knowledge, wisdom, and judgment of farm families on the land.

Two things happen when farmers become overdependent on petro-industrial inputs: emissions go up, and incomes go down.

Low-input agriculture: toward solutions to the climate and farm crises

In addition to a big-picture look at the causes of the farm and climate crises, this report also contains detailed plans for helping ease both—dozens of specific, concrete actions. It contains a catalogue of on-farm measures and government policies that can, as a package, reduce GHG emissions from Canadian farms by approximately 30% by 2030 and perhaps by 50% by 2050. These potential measures and policies include:

- Reimagining Canadian agriculture: rejecting current policies focused on maximizing exports and production, maximizing inputs, and minimizing the number of farmers; and substituting a new approach focused on sustainability, reducing inputs and attendant emissions, raising farm incomes, and increasing the number of farms and farmers.
- Diversifying our production approaches by supporting alternatives such as organic, holistic, and agroecological production systems.

- Increasing the efficiency of fertilizer production and use, maximizing natural sources of fertility, reducing fertilizer consumption, and providing alternatives to purchased inputs.
- Encouraging the use of cover crops, intercropping and multi-cropping, and enhanced rotations.
- Shifting, as much as possible, from fossil fuels to electricity, because electricity can be a low-emission power source. This means that we need to look at electric farm machinery: trucks and smaller equipment, and also small and medium-sized tractors.
- Increasing the efficiency of all on-farm energy use and retrofitting homes and farm buildings.
- Maximizing on-farm renewable-energy production as well as locally and co-operatively owned large-scale solar and wind power projects.
- Reducing food waste, minimizing over-processing and denutritionalization of food (corn puffs and sugar snacks) rethinking biofuels, and looking critically at bioenergy and biomaterials schemes.
- Minimizing transport distances and rejecting the senseless toing and froing of food, export-fixated agricultural policies, the destruction of local food systems, and the maximization of food miles.
- Shifting some land into set-aside programs, ecological reserves, and alternative land use systems (ALUS) and reversing the destruction of forests, tree bluffs, shelterbelts, and wetlands.
- Better managing manure, thus reducing emissions from that source.
- Rethinking cattle production systems in order to maximize the benefits (soil carbon building, healthy grassland ecosystems, sustainable mixed farms) while taking steps to deal with methane emissions.
- Minimizing the unnecessary and indefensible release of methane by the global oil-and-gas sector in order to make emissions space for cattle and other ruminants.
- Opening a conversation with farmers to consider how a carbon tax might be applied to agricultural inputs in a way that supports farm incomes; incentivizes a move toward low-input, low-emission approaches; financially rewards those who invest in emission-reduction technologies and retrofits; and helps speed a transition to sustainable production systems.
- Creating a Canadian Farm Resilience Administration (CFRA)—a *super PFRA* (Prairie Farm Rehabilitation Administration)—to help farmers protect soils, land, water, and our food-production capacities; support moves toward alternative land use, including wetland restoration and afforestation; and assist in the mobilization needed to meet our emission-reduction targets and stabilize our climate.

Farmers have a choice: take an active, lead role in discussions and implementation of emissions solutions, or cede control to others. Some people will make the case that agriculture is special—so important that it should be exempt from the need to cut emissions. But every sector of the economy will try to make that same case and promote the status quo. Agriculture produces 12% of Canadian emissions. As our country works to cut its emissions by 30% or more by 2030 and to net zero by mid-century, agriculture, like other sectors, will have to make transformative changes. The physics of the atmospheric systems force upon us the realization that (agri)business as usual is not an option.

Our last chance to save the family farm

The policies and measures to reduce agricultural emissions summarized above and detailed below will raise concerns for many farm families. How will new approaches, government policies, taxes, and regulations impact their fragile financial positions? How can cash-strapped farmers find money to invest in new technologies and machinery? How can we transform and restructure agriculture when many of us are struggling just to stay afloat? The NFU does not discount these uncertainties and fears. The NFU is an organization of farm families. Its democratically-elected leaders are farmers—men, women, and youth who struggle every day with the many problems and worries that come with a life on the land. We do not underestimate the challenge. But the scale of the threat—ecological and economic devastation—means that rapid, aggressive action is far better than inaction. The transformations we have outlined in this report, and that we farm families must undertake in coming decades, will create risks. The NFU has drawn a roadmap intended to protect farm families, ecosystems, and future generations. That said, it is simply not possible to create a plan that transforms agriculture yet leaves it unchanged, that replaces large parts of our machinery stock but incurs no costs, or that spurs rapid change but creates no uncertainty or dislocation. We have done our best to chart a course into the future, but our journey is not without perils and uncertainties. It is not without costs and sacrifices. The costs of the proposed actions, however, will be far lower than the cost of inaction or inadequate action—far lower than the costs of climate chaos and scorched fields.

High-input agriculture is destroying the family farm and producing emissions that will destroy climate stability and economies and societies around the world. Low-input agriculture can free farmers from the profit-extracting embrace of corporate input suppliers, reduce costs, increase net farm incomes, and reduce emissions. At the heart of this report is an idea—a radical idea: Though a threat, the climate crisis is also an opportunity. It forces change upon us and this creates a chance—probably our last—to save the family farm. The climate crisis provides the opportunity and reason to partially unhook from the corporate input suppliers that are draining our farms and rural communities of their financial lifeblood and their populations. The National Farmers Union does not underestimate the climate risks we face or the uncertainties farm families must now endure, but we do want to say something that perhaps no other farm organization will say:

In this historical moment, as the physics of our atmosphere and climate system force us to reduce energy use and emissions, farm families have a chance, perhaps the last we will ever have, to break free from the corporations that extract our wealth, decimate our numbers, endanger our farms, indebt our futures, weaken our communities, and force our children to leave their farms.

Reducing input use, a key part of the solution to the climate crisis, is also the solution to the farm crisis.

We need to act *now*

We have known about climate change for decades. For example, more than three decades ago, in 1988, Canada hosted the world's first large-scale climate conference that brought together scientists, experts, policymakers, elected officials, and the media. The World Conference on the Changing Atmosphere issued a final communique which stated that "humanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war." That same year governments and scientists came together to form the United Nations Intergovernmental Panel on Climate Change (IPCC), and NASA scientist Dr. James Hansen told a US congressional committee that climate change and global warming were already underway and that he was 99% certain that the cause was a buildup of carbon dioxide and other gases released by human activities. More than 30 years later we have not only failed to act on this information, we have made the situation worse by increasing our emissions to record levels. We are in the fourth decade of the climate crisis. Nothing in this report should seem new.

Nor have the NFU and its farm family members only recently turned our attention to climate change. In a report to Canada's Senate Committee on Agriculture and Forestry in February 2003—nearly 17 years ago—the NFU outlined the problem concisely:

> *We have constructed the most energy-inefficient food production and distribution system in human history. And each year, we increase the energy usage in, and greenhouse gas emissions from, our food system. Its energy-inefficiency (and inefficiencies in every other sector of our economy and society) now threatens to destabilize the natural systems upon which food production is based and to dramatically reduce the amount of food available to Canadians and to people around the world.*

> *Further, food production uncertainties resulting from human-induced climate change will manifest themselves at exactly the same time that humanity adds another three billion to its number. This combination of human-induced climate change, destabilized food production, water shortages, human population growth, and potential economic instability will strain, not only our ability to feed ourselves, but the very foundations of our civilizations. Climate change is a huge threat to Canada and other nations.*
>
> *Human-induced climate change also raises profound ethical issues: the most damaging effects of climate change—famine and economic collapse—will fall predominantly on the poorest nations, while it is predominantly the richest ones that created the problem.*
>
> *Finally, human-induced climate change threatens to unleash ecosystem loss and species extinction unparalleled in millennia.*
>
> *It is impossible to overstate the importance of taking swift action to deal with human-induced climate change.*

After 17 years of rising energy consumption and rising emissions from agriculture, it remains "impossible to overstate the importance of taking swift action to deal with human-induced climate change."

Although transformative change to cut emissions and stabilize our climate brings risks, it also opens the way for rewards. The necessary changes ahead bring the possibility of refocusing our farm and food systems—away from the push to increase yields, production, exports, and trade and toward increasing farm incomes and the number of people on the land taking care of the soil, water, and other species. ***We are looking at a future wherein agriculture must increasingly re-merge with nature and culture to create a much more integrated, life-sustaining, and community-sustaining agroecological model of human food provision, nutrition, and health.*** So, in reading this report, do not imagine the current world with some emissions-lowering techno-tweaks or some solar-panel incentives. Imagine a transformed world. This report is an initial roadmap to begin to navigate that transformation.

Chapter 1: The Farm Income Crisis

Nearly a third of Canadian farm families have been forced off the land in just one generation

This report begins by looking at the farm income crisis and examining how our high-output, high-input, high-energy-use, high-emission food-production system transfers farm wealth to transnational input-supply corporations. Using ever-larger quantities of fertilizers, fuels, chemicals, plastics, and other purchased inputs increases emissions and lowers net incomes.

Net farm income

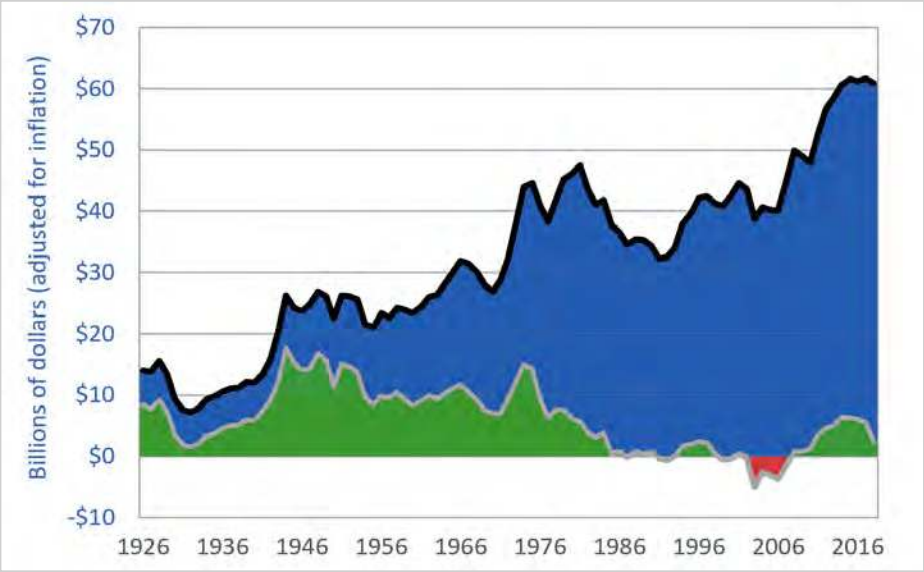

Figure 1-1. Gross farm revenue and realized net income, net of government subsidies, Canada, 1926–2018
Sources: Statistics Canada Tables 32-10-0045-01 (formerly CANSIM 002-0001); 32-10-0052-01 (002-0009); 32-10-0106-01 (002-0076); and 32-10-0153-01 (004-0002)

In the 33-year period from 1985 to 2018, input costs consumed more than 95% of farm revenue and left farmers with just 5%. Farmers were urged to adopt a high-input, high-output productivist model, and this empowered extractivist corporations to pocket nearly $1.5 trillion dollars of the value created by Canadian farms since 1985. Figure 1-1 shows Canadian farm revenue and income over the past 92 years. The graph features two lines. The top line, in black, shows farmers' gross revenues, with government subsidies subtracted. This is the money farmers received from the markets when they sold crops, livestock, potatoes, vegetables, honey, eggs, milk, and other products. The lower line, in grey, shows farmers' realized net incomes, again with government subsidies subtracted. This grey line represents the market revenue farmers had left after they paid their expenses (but often before they paid themselves or their family members). All figures are adjusted for inflation.

The graph highlights periods of positive net farm income in green, and periods of negative net income in red. The most important part of the graph is the area coloured dark blue: this top portion, between the upper black and lower grey line, represents the difference between farmers' gross revenues and their net incomes. The blue represents farmers' *expenses*—the amount they pay for inputs and services, the amount captured by Bayer-Monsanto, John Deere, Nutrien, the banks, etc. That blue area has grown. The agribusiness corporations selling inputs and services are capturing an ever-larger share of farmers' revenue.

Yield, production, and revenue go up, but net income stays flat, or goes down, as farmers pay out more for inputs. Since the mid-1980s, realized net farm income from the markets has oscillated near zero, recovering only weakly in recent years before declining again in 2018.

The graph's clear message is that the 40+ year experiment in high-output, high-input, high-cost food-production has been a bust for farmers. It has often reduced their net incomes to near zero and, as detailed below, it has multiplied debt levels and reduced the number of farm families on the land by a third in a single generation. Even if a person wanted to ignore the data and assert that farmers are "doing okay," the 95%-vs-5% revenue split between agribusiness and farmers should raise concerns.[2]

Farm debt

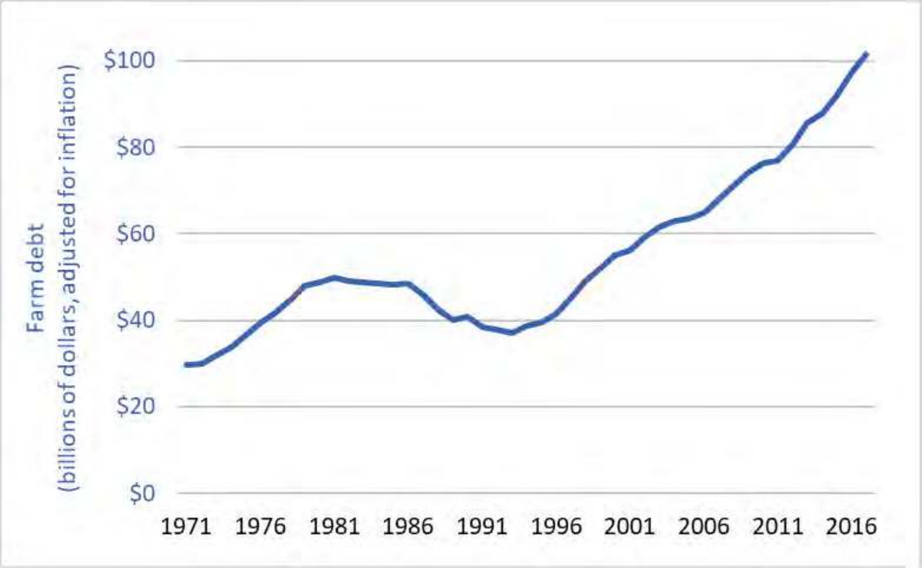

Figure 1-2. Farm debt, Canada, 1971–2018
Sources: Statistics Canada Table: 32-10-0051-01 (formerly CANSIM 002-0008)

Canadian farm debt is just over $106 billion, a record high, having nearly doubled since 2000. (All figures and comparisons are adjusted for inflation.)

Since 2000, farmers' realized net income from the markets has averaged $1.5 billion per year. Over this same period, farmers have taken on additional debt (i.e., they have borrowed money without repaying it) at a rate averaging $2.7 billion per year. Farmers have dealt with their inadequate cashflows by borrowing from the banks (i.e., from the future). Every dollar in net income has been augmented by 1.8 dollars in additional cashflow in the form of new, unrepaid debt.

Worse, the amount farmers pay annually in interest to banks and other lenders has been roughly equal to the amount that Canadian citizens each year pay to farmers via farm-support programs. In effect, taxpayers are paying farmers' interest bills—transferring tens-of-billions to banks and other lenders.

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[2] Due to difficulties in accessing consistent, long-term data, the preceding does not fully account for non-arms-length (i.e., family) wages—about $1 billion to $2 billion per year. Taking full account of those amounts, however, would not change the conclusions above. The graph would look the same.

Seen another way, every year farmers take on additional debt roughly equal to the amount they are required to pay in interest to banks. In effect, for the past two decades banks have been loaning farmers the money needed to pay the interest on tens-of-billions of dollars in farm debt.

With farm debt now more than $106 billion, with debt increasing by an average of $2.7 billion per year, with interest payments of $2.6 billion per year, and with realized net incomes from the markets averaging just $1.5 billion per year, the Canadian farm sector may be insolvent. It appears unlikely that farmers can service their $106 billion debt without government/taxpayer assistance.[3]

Off-farm work and the other sources of farm family income

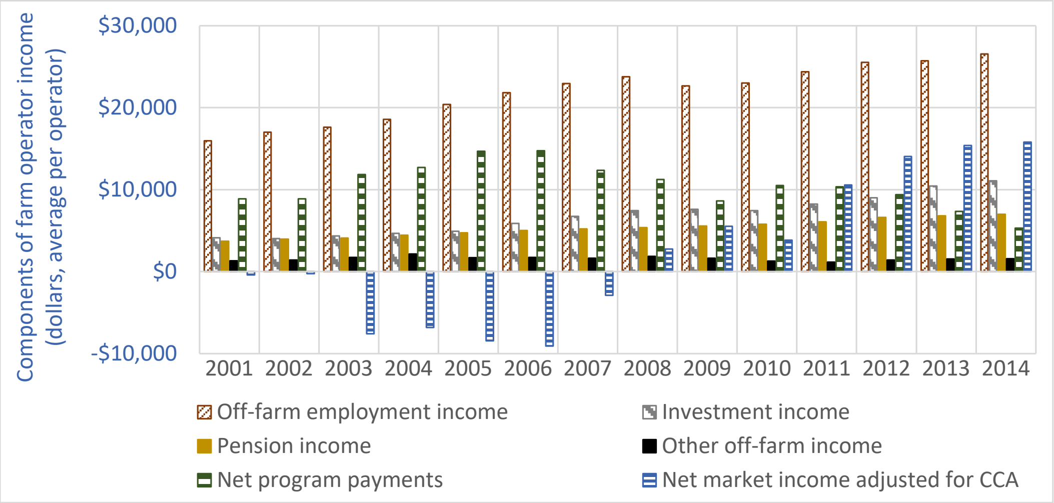

Figure 1-3. Incomes of farm operators, by source, unincorporated and incorporated farms, 2001–2014
Source: Statistics Canada Table 32-10-0068-01 (formerly CANSIM 002-0034)

Input costs drain away 95% of farmers' market revenues. To make ends meet, farmers have been forced deeply into debt and most farm families must also rely on off-farm sources of income.

Figure 1-3 shows the components of the incomes of farm operators—the men, women, and youth who own, work on, and/or manage Canadian farms. The graph shows farm operator income from various sources: off-farm employment income, pensions, investments, and farm-support program payments. The numbers are for operators on both incorporated and unincorporated farms. The values are not adjusted for inflation. Data after 2014 is not currently available.

The years since 2007 are often characterized as "better times" for Canadian farmers. This is true for some; a number of farm families have prospered in the recent decade and some have even grown rich. Figure 1-3 shows that net farm income turned positive in 2008 and has remained positive. However, the graph also shows that that even after 2007 off-farm employment and non-farm income continued to make up the bulk of operator income: off-farm employment contributed 41%, investment income contributed 15%, pension income contributed 10%, and farm-support-program payments contributed 15%. Net market income contributed just 16%. (Net market income excludes farm-support payments, and is adjusted for capital cost allowance (CCA) to account for depreciation of assets such as machinery.)

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[3] For details on whether farm families are "doing okay," see "Appendix A: Farm income: Are things so bad down on the farm?"

Loss of family farms

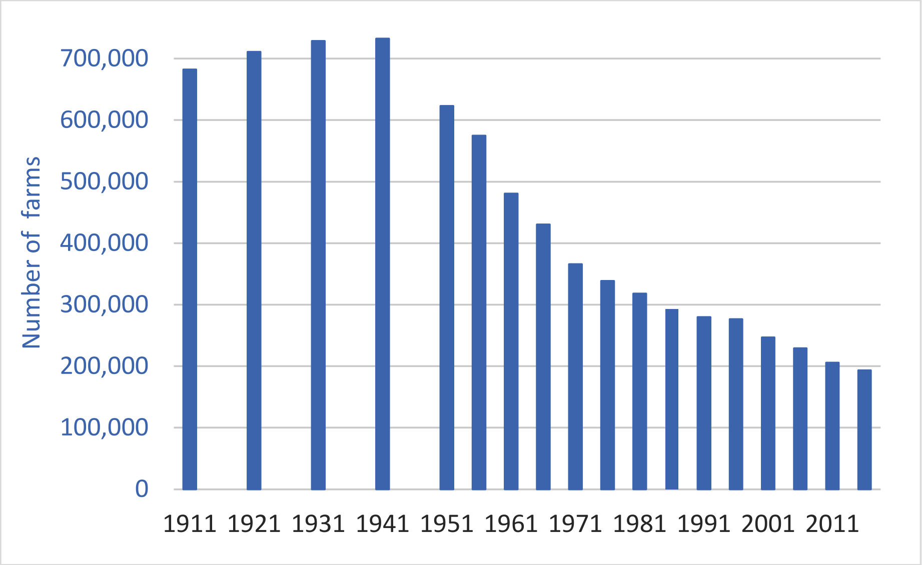

Figure 1-4. Number of farms ("farm operations"), Canada, 1911–2016, Census years
Source: Statistics Canada Table: 32-10-0152-01 (formerly CANSIM 004-0001)

With costs high, net income low, and debt rising, it is no surprise that farm families are being forced off the land. Nearly a third of Canadian farm families have been expelled in just one generation (Figure 1-4). There are fewer than 193,000 farms in Canada today, down from 280,000 28 years ago. The loss is even more dramatic in many provinces. Prince Edward Island and Manitoba have lost *half* their farmers since 1986. Saskatchewan has lost nearly half since 1981. At this rate, there may be just 100,000 farms in Canada by mid-century—half the current number. If current government policies and agribusiness practices continue, far less than one percent of Canadians will remain on our farms by the 2050s.[4]

We can understand the loss of farmers in another way: not as a loss, per se, but as a *shift* in employment from farms to input-supply companies—a shift in employment that has followed the transfer of profits. Nearly 95% of farm revenue is extracted by seed, chemical, fertilizer, and machinery companies, banks, etc. As agribusiness companies extract more and more farm wealth, these companies and their workforces grow, at the expense (literally) of farm families.

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[4] 100,000 farms might mean a farm population of 300,000 people. With total Canadian population projected at 44 million, the farm population would be 0.68%.

The loss of *young* farmers

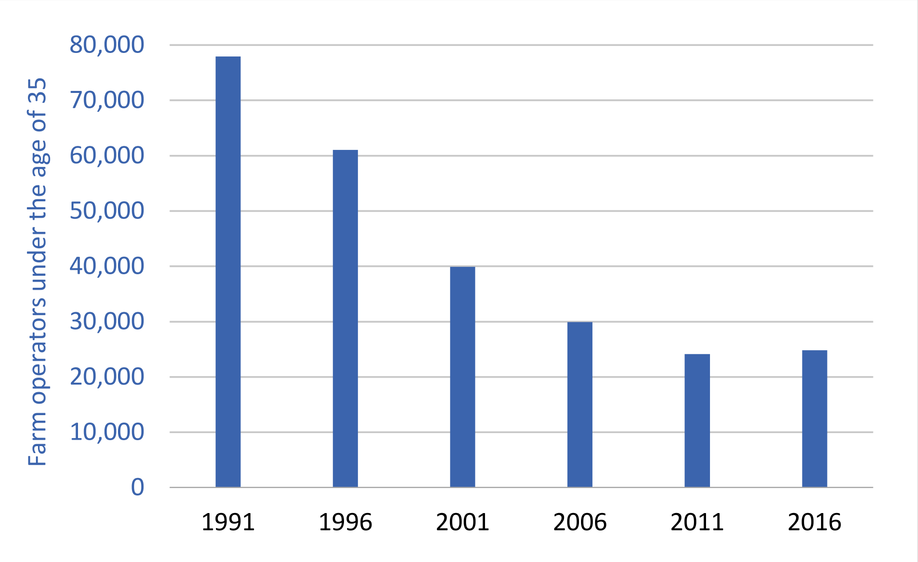

Figure 1-5. Number of farm operators under 35, Canada, 1991–2016, Census years
Source: Statistics Canada Table 32-10-0169-01 (formerly CANSIM 004-0017)

It is bad enough that many Canadian provinces have lost half their farmers in a generation. Far worse, Canada is losing young farmers *twice as fast*. The number of young farmers (ages of 15 to 34, inclusive) has been cut by 68% over the past 25 years (Figure 1-5). Though the number has perhaps stabilized since 2011, Canada's 25,000 farmers under the age of 35 are far too few to sustain a thriving farm sector two or three decades down the road. This small number of young farmers is consistent with overall farm numbers falling to about 100,000 by mid-century.

Low margins, high costs, expensive machinery and farmland, relentless wealth extraction by the dominant agribusiness transnationals, regressive federal and provincial agricultural policies, and other factors create huge barriers to entry for young farmers and often unendurable pressures to exit. Unless we move quickly to transform agriculture to increase net incomes, Canadian family farms will plunge off a demographic cliff.[5]

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[5] For a detailed exploration of the challenges facing farm youth, please see D. Qualman, A. Akram-Lodhi, A. Desmarais, and S. Srinivasan. "Forever Young? The Crisis of Generational Renewal on Canada's Farms," *Canadian Food Studies* 5, no. 3 (2018).

The farm crisis, and the climate crisis

Canada's high-output, high-input, high-energy use, high-cost food-production experiment has been a bust for the vast majority of Canadian farm families. It has reduced the number of farmers by a third; reduced net incomes from the markets to near zero or below in 19 of the past 32 years; raised debt levels to record highs; expelled sons and daughters from their farms and communities; forced farmers and their spouses to work off-farm jobs to support their families; transferred approximately $1.5 trillion in food-production wealth to input-supply corporations; and required more than $100 billion in taxpayer-funded support payments just to keep the system solvent.[6]

Perhaps even more damaging in the long run and for the planet, our maximum-output, maximum-input, maximum-energy-use food-production system has also created record-high greenhouse gas (GHG) emissions. The climate crisis requires that we slash GHG emissions from *every sector* of the Canadian economy, and from every economy worldwide. We must reimagine, restructure, rewire, and retool our farms and food systems.

Farmers will be justifiably uneasy about the potential risks, costs, and uncertainty created by the need to decarbonize and transform Canadian agricultural systems. At the same time, it is critical to understand that *the climate crisis is also an opportunity* for farm families. To reduce emissions, we must end farmers' massive overdependence on emission-causing petro-industrial inputs: fuels, fertilizers, chemicals, plastics, and other purchased products. And as we reduce input overuse, we have the opportunity to *increase* net farm income—to raise farmers' share, beyond the 5% of gross revenue farmers have averaged over the past three decades, to perhaps 15 or 20%. In the period from 1945 to 1975, farmers' share of gross revenue was 45% (Figure 1-1). In 2018, agribusiness input suppliers extracted $58 billion from Canadian farms. What if $5 or $10 billion had instead stayed on our farms and in our rural communities? Imagine the Canadian farm renaissance that will be created if we can manage to triple or quadruple farmers' net incomes from the markets!

The climate crisis provides the opportunity and impetus to partially unhook from the global input syndicate—the increasingly powerful cabal of merging, monopolistic corporations that are draining our farms and rural communities of their financial lifeblood and populations. The National Farmers Union does not underestimate the profound climate risks we face. Nor do we want to downplay the uncertainty and worry that farm families must now endure. But we do want to say something that perhaps no other farm organization will say:

In this historical moment, as the physics of our atmosphere and climate system force us to reduce energy use and emissions, farm families have a chance, perhaps the last they will ever have, to break free from the corporations that extract our wealth, decimate our numbers, endanger our farms, indebt our futures, weaken our communities, and expel our children.

This moment of potential energy- and food-system disruption and *transformation* is perhaps farm families' last chance for liberation. The climate crisis and the need to reimagine a new, low-emission, low-input model of food production opens a door for our escape. Embracing rather than resisting change offers an opportunity to raise net incomes and to ensure that family farms remain the primary unit of food production in Canada throughout the 21st century. Though the perils are many, the climate crisis creates one last chance to save the family farm.

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[6] Tax-funded farm-support program payments totalled $112 billion between 1985 and 2018.

Chapter 2: The Climate Crisis

Humans are causing CO_2 levels to rise 10 to 100 times faster than those levels have increased at any time in the past 800,000 years.

Carbon dioxide levels

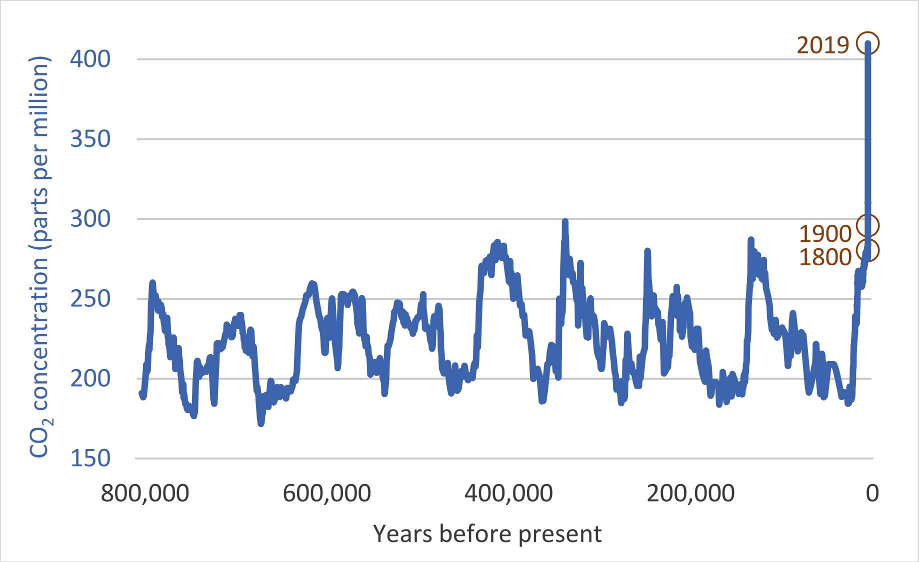

Figure 2-1. Atmospheric carbon dioxide concentration, 800,000 years ago to present
Sources: A. 800,000 years ago to 1913: Ice core samples, Dome C, Antarctica (Monnin et al. 2001; Siegenthaler et al. 2005; Luethi et al.) and Vostok, Antarctica (Petit et al. 1999; Pepin et al. 2001; Raynaud et al. 2005); B. 1832–1978: Ice samples, Law Dome, Antarctica; C. 1959–2019: Direct measurements, Mauna Loa Observatory, NOAA.

We know the following for sure, without doubt, and beyond dispute: atmospheric greenhouse gas levels today are much higher and rising much faster than at any time in the past 800,000 years—a period four times longer than our species, *Homo sapiens*, has walked the Earth.

Figure 2-1 shows that over the past 800,000 years, levels of the greenhouse gas carbon dioxide (CO_2) have risen and fallen. The low levels visible in the graph correspond to glacial periods (often called "ice ages"); eight such periods are visible. Higher CO_2 levels correspond to largely ice-free interglacial periods. Though CO_2 levels fluctuate, the critical point is this: in the 800,000 years before the 20th century, CO_2 levels *never once rose above 300 parts per million (ppm)*. Not once. Now, however, as a result of fossil-fuel combustion and other activities, CO_2 levels have shot past 415 ppm.

Not only are CO_2 levels high, they are rising rapidly. Note on the right-hand side of the graph the CO_2-level increase from its minimum level of about 180 ppm to 280 ppm around the year 1900. That rise of just over 100 ppm took 16,000 years. Now note the rise since 1900—again about 100 ppm. This latter increase has taken place in just over a century. Humans are causing CO_2 levels to rise 10 to 100 times faster than those levels have increased at any time in the past 800,000 years. We are not witnessing "natural fluctuations."

There can be no doubt that greenhouse gas levels are rising and that humans are the cause. It is impossible to look at the graph above and come to any other conclusion. The consequences of the fossil-fuelled industrial and transportation revolutions of the 19th, 20th, and 21st centuries are clearly visible in the graph's vertical spike.

Temperature increases

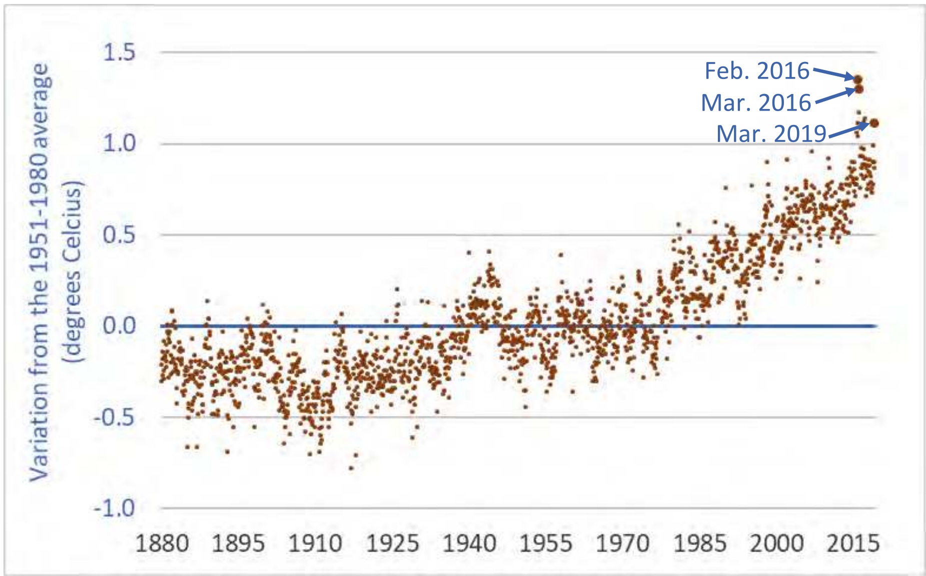

Figure 2-2. Temperature increases, global land and ocean surface, monthly, 1880–2019
Sources: NASA Goddard Institute for Space Studies, GISS Surface Temperature Analysis (GISTEMP)

As CO_2 levels rise, so do temperatures. Figure 2-2 shows how global average temperatures are increasing. (Technically it shows the global average “temperature anomaly”: how land and ocean surface temperatures compare to the 1951-1980 “normal.”) Four things are apparent:

1. Earth is already warming.
2. Temperatures are rising rapidly, with large increases taking place over decades, not centuries or millennia. The increase in temperature from the 1951–1980 reference period will soon reach one degree Celsius, perhaps reaching this point in as little as 10 years. February and March 2016 approached 1.5 degrees.
3. The rate of temperature increase may be accelerating. A close look at the graph suggests that its curve may be getting steeper, which is not surprising given that our rate of emissions is accelerating.
4. We can expect planetary heating to continue for some time. Global temperature increases lag well behind increases in atmospheric GHG levels. This means that warming will continue for a long time even if we stop emitting GHGs, and it means that rates of temperature increase may accelerate beyond already-rapid rates.

Rural Canada's future climate

How high will temperatures rise? We have a good sense of the answer: Taking into account all current commitments and actions on the part of governments in Canada, the US, the EU, and the other nations of the world, agricultural areas in the Maritimes, Ontario, Québec, and coastal British Columbia can expect temperature increases of 3.2 degrees Celsius above pre-industrial levels, this century. Even more concerning, farmers in the Prairies and some parts of BC can expect increases of 6.4 degrees Celsius this century. These levels of increase, if they come to pass, will be absolutely devastating—damaging or terminating food production in many of Canada's agricultural regions. But we can act to head off these large increases. We can move aggressively to reduce emissions faster and thereby restrain temperature increases. But what is important to understand is this: ***as things stand now, given existing national and global GHG-emission-reduction policies and commitments—including all carbon taxes and electric car incentives and other policies in place or announced—we are on track to increase average temperatures on Canadian farms by 3.2 to 6.4 degrees Celsius.***

How do we know this?

Predicting the magnitude of future temperature increases requires understanding the emission-reduction commitments that have been made by governments around the world. This is because current and future levels of emissions—and our successes or failures in reducing them—will determine global and regional temperatures 20, 50, or 100 years from now.

In the lead-up to the December 2015 United Nations (UN) Paris climate talks (the "COP 21"), nearly all nations made formal emission-reduction commitments—submitting to the UN their reduction targets for 2020, 2030, and beyond. The technical term for these commitments was "Intended Nationally Determined Contributions" (INDCs). Once all the commitments were submitted, scientists and technicians updated their computerized climate models based on the promised emissions reductions[7] and used those climate models to predict global average temperatures to the end of the 21st century.

What those climate models predict is alarming. Even if all governments do as they have promised and all emissions reductions are achieved, the global temperature increase will nevertheless reach 3.2 degrees Celsius above pre-industrial levels by the end of the century.[8]

Again: Even if all nations act with speed and integrity and fully meet their Paris commitments to cut emissions, predicted global average temperatures will rise, not by 1.5 degrees Celsius, and not by 2 degrees. No, global temperatures will rise by 3.2 degrees Celsius in the coming 80 years. This is the path we are on.

Bad as this news is for the planet, the news is even worse for most Canadian farmers—especially those in the Prairie region. The Earth is not warming uniformly; continental interiors and higher latitudes—including the Canadian Prairies—are warming twice as fast as the global average.[9] So a 3.2 degree rise in the global average temperature this century may well mean a 6.4 degree rise for Manitoba, Saskatchewan, Alberta,

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[7] In some cases, nations committed to slower emissions *increases* rather than outright reductions. See UNFCCC NDC registry, https://www4.unfccc.int/sites/NDCStaging/Pages/All.aspx .

[8] United Nations Environment Program (UNEP), *The Emissions Gap Report 2018* (Nairobi, Kenya: United Nations Environment Program (UNEP), 2018), www.unenvironment.org/resources/emissions-gap-report-2018 .

[9] F. Warren and D. Lemmen, *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (Ottawa: Government of Canada, 2014), 6, http://epe.lac-bac.gc.ca/100/201/301/weekly_checklist/2014/internet/w14-26-U-E.html/collections/collection_2014/rncan-nrcan/M174-2-2014-eng.pdf .

the Peace River region of British Columbia, and perhaps even some parts of Ontario. Such a huge and rapid increase would be cataclysmic. And it is farmers, our land, and our livelihoods that are most vulnerable.

Even worse, this 3.2 to 6.4 degrees of warming will not affect our climate and our weather in a uniform, predictable way. More warming may come in the summer than the winter, more in some years than others. Rains may be more intense or snows heavier. We may have more flooding and more perennially flooded land. Hotter temperatures may dry the land midsummer, and cause crop losses due to drought. The more the climate warms, the more probable become devastating multi-year droughts in many Canadian regions. What would three or four years of back-to-back crop failures or very low yields mean to Canadian farms burdened with $106 billion in debt?

If we do not cut energy use and GHG emissions in agriculture and throughout the economies of Canada and other nations, atmospheric GHG levels and temperatures will keep rising. The Prairie Climate Centre's *Climate Atlas Project* forecasts that if we continue on a high-emission pathway, the climate on the Canadian Prairies could come to resemble that of current-day northern Texas.[10]

It is impossible to overstate the calamity such scenarios imply. In the face of such projections it is wrong to remain calm. Alarm is the proper response. Immediate, aggressive action is the only responsible course. Climate changes of these magnitudes, if we allow them to occur, will deliver *body-blows* to the production capacity and finances of our family farms. The emissions trajectories we are on—even factoring in all policy measures implemented or announced—will lead to catastrophic levels of warming that, if not averted, will bring so much instability and peril that adaptation will be impossible and the survival of large parts of our farming sector will become an open question. Farmers will be among the hardest hit if climate change is not controlled and emissions slashed. We are on track to permanently destroy our future. All we have to do to ensure that this disaster occurs is nothing.

These worst-case scenarios, however, *can* be averted. We should be alarmed, but we must not despair. Immediate, effective actions to reduce greenhouse-gas emissions from our farms, food systems, and from other sectors of our economy can lessen the danger and damage. We have the knowledge, technologies, options, and alternatives to allow us to succeed in this endeavour. We must act *now*, and with almost unprecedented levels of commitment and effectiveness.

Farmers, other citizens, all sectors, and all levels of government must mobilize, with near-wartime-levels of commitment and effectiveness, to slash emissions.

We need to get busy. We need to understand the sources of our GHG emissions and we need to formulate and implement plans to rapidly reduce those emissions. All sectors of our economy and all nations must cut emissions. And farm families must take a lead role in reducing agricultural emissions, and we must take a lead role in helping create and manage the policies that move us to lower-energy-use, lower-emission, higher-net income farm and food systems.

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[10] Henry Venema and Danny Blair, "Climate Atlas Pinpoints Change," *Winnipeg Free Press*, November 28, 2015.

Chapter 3: Greenhouse Gas Emissions

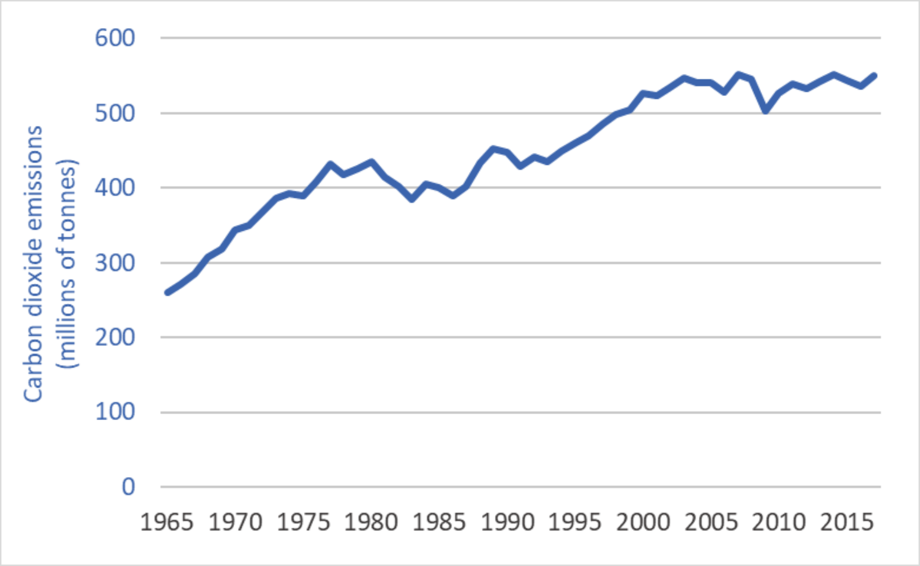

Figure 3-1. Canadian carbon dioxide (CO_2) emissions, 1965–2018
Sources: British Petroleum, *BP Statistical Review of World Energy 2019* (London: BP, 2019)

Carbon dioxide (CO_2) is the main greenhouse gas (GHG), responsible for approximately 70% of climate warming. Consequently, our emissions of that gas will largely determine our future climate. Figure 3-1 shows Canada's CO_2 emissions from 1965 to 2018. In 2018, the households and businesses of Canada emitted a near-record-high quantity of CO_2. Our emissions are up 13% since 1997, the year our nation and others signed the Kyoto Protocol. Under that agreement, Canada pledged to reduce its total GHG emissions to 6% below 1990 levels by 2012. Had we met that target, Canadian CO_2 emissions would now be approximately 400 million tonnes per year, instead of 550 million.

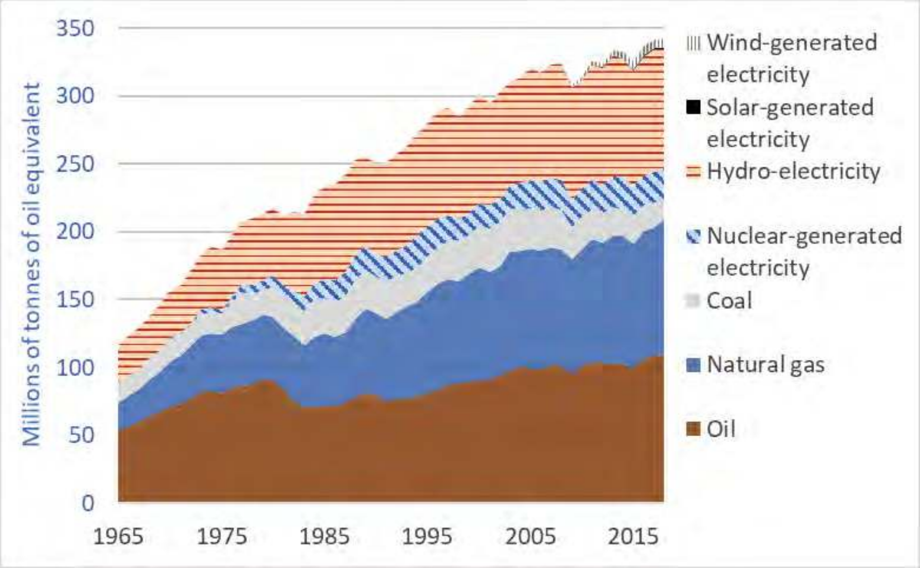

Figure 3-2. Canadian energy use, 1965–2018
Source: British Petroleum, *BP Statistical Review of World Energy 2019* (London: BP, 2019)

In 2018, Canadians consumed a record quantity of fossil fuels: coal, natural gas, and oil—the bottom three categories in Figure 3-2. Look also at the top two categories: new, low-emission renewables—wind- and solar-generated electricity. Wind contributes a tiny amount to Canada's energy supply, only about 2%. Worse still, virtually invisible in the graph is a black line representing solar-generated electricity. Though it is growing fast, solar power provides just 0.2% of Canada's energy supply. We are increasing our use of natural gas much faster than we are increasing our use of solar power.

The emissions picture gets slightly better when we look at all greenhouse gases, not just CO_2—when we look at Canada's total emissions. Figure 3-3 shows total Canadian emissions: carbon dioxide, nitrous oxide, and methane, as well as several lesser GHGs. Canada has reduced total GHG emissions slightly; emissions in 2017 were down 3.7% from their peak in 2007. But it is hard to look at Figure 3-3 and see a clear downward trendline. If anything, it appears that Canadian emissions have been more-or-less flat

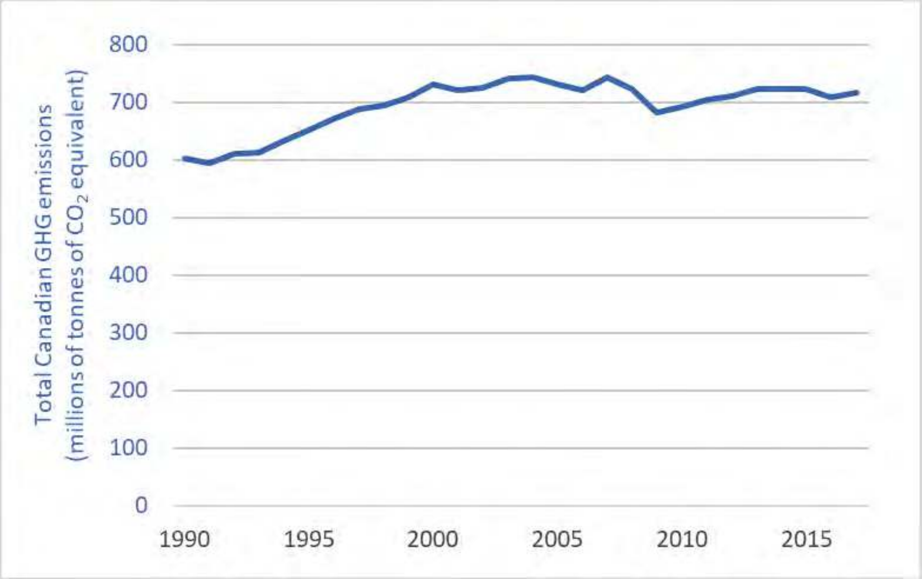

Figure 3-3. Total Canadian GHG emissions (CO_2, N_2O, and CH_4), 1990–2017
Source: Environment and Climate Change Canada, "Canada's Official Greenhouse Gas Inventory," http://data.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/?lang=en

Whether or not Canada has reduced its overall emissions, our emissions remain very high. Per capita, Canada's emissions are among the highest in the world. A 2018 report by Climate Transparency[11] compared emissions from G20 members. The *Globe and Mail* summarized the report's findings:

> *Canada's push to be an international leader in the fight against climate change may be hampered by a distinction that it produces the most per-person greenhouse gas emissions among G20 economies. … The [Climate Transparency] analysis says, on average, each Canadian produces 22 tonnes of greenhouse gas per year–which is the highest among all G20 members and nearly three times the G20 average of eight tonnes per person.*[12]

Canada's current emission-reduction commitments

Various Canadian governments have made numerous commitments to reduce GHG emissions. In the lead-up to the 2015 Paris climate talks (the "COP 21") Canada pledged to reduce emissions by 30% (below 2005

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[11] Climate Transparency, *Brown to Green: The G20 Transition to a Low-Carbon Economy* (Berlin: Climate Transparency, 2018), https://www.climate-transparency.org/wp-content/uploads/2019/01/2018-BROWN-TO-GREEN-REPORT-FINAL.pdf .

[12] "Canadians Produce Three Times More Greenhouse Gas Emissions than G20 Average," *Globe and Mail*, Nov. 14, 2018, www.theglobeandmail.com/canada/article-canada-found-to-produce-most-greenhouse-gas-emissions-per-person-among/ .

levels) by 2030. That deadline is now just a decade away. The Canadian government has also acknowledged the deep decarbonization necessary by mid-century. In September 2019, Prime Minister Justin Trudeau committed to making Canada "carbon neutral" by 2050.[13] Carbon neutral means that overall net emissions would be zero. While some sectors would continue to emit (farm tractors, perhaps) negative-emissions activities elsewhere such as afforestation or direct air capture of CO_2 (the latter being highly speculative) would reduce Canada's net emissions to zero. Getting to net zero in three decades will require Herculean efforts and the restructuring of every production and energy system.

In addition to specific emission-reduction commitments, in Paris in 2015 all governments committed to "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C…."[14]

Finally, many Canadian cities and provinces have made their own very ambitious commitments to reduce GHG emissions in coming years and decades.

These commitments, combined with the rapid warming already underway and predictions of several degrees of warming this century, mean that it is unrealistic to take the position that Canadian agriculture can assume business-as-usual in the 2020s, the 2030s, and beyond. These commitments to 30 or 50% reductions in GHG emissions and to net zero emissions by 2050 mean that Canadian agriculture will be *transformed* in the next two or three decades. The question is: Who will lead and manage that transformation? Will it be farm families? …distant governments? …or agribusiness corporations? ***Farmers must act quickly, ambitiously, and collectively to advance solutions or else they will surrender leadership and control to others.***

A GHG primer

There are three main human-made ("anthropogenic") greenhouse gases (GHGs):

1. Carbon dioxide. CO_2 comes mainly from the combustion of fossil fuels (oil, natural gas, and coal): from exhaust pipes on cars, trucks, or tractors; from electricity-generation plants that burn coal or natural gas; and from homes that burn natural gas in furnaces. CO_2 is also emitted from manufacturing concrete, fertilizer, and other materials. It can be released from soils when forests are cut or grasslands broken. CO_2 is responsible for 70% of warming. It persists for a long time—affecting the climate for centuries.

2. Nitrous oxide. N_2O comes mainly from fossil-fuel combustion, nitrogen fertilizer use, and manure management. Though the tonnage of N_2O emitted is much less than that of CO_2, N_2O contributes significantly to warming because tonne-for-tonne its warming effect is 265 times more powerful than CO_2.

3. Methane. CH_4 comes primarily from four sources: coal, oil, and gas production (natural gas is mostly methane); landfills; rice paddies; and livestock production—emitted from the mouths of cows as they digest grass ("enteric methane") and, to a lesser extent, from manure.

And what is CO_2e? We often see GHG emissions reported in units of "CO_2 equivalent" or "CO_2e." This means that GHGs such as methane and nitrous oxide have been included as if they were a quantity of CO_2 that would have a warming effect equal to that quantity of methane or nitrous oxide. For example, because the warming effect of nitrous oxide is 265 times as high as that of an equal weight of CO_2, a tonne of nitrous oxide is recorded as 265 tonnes CO_2e. As an analogy, think of currencies. If we were recording expenditures from many nations in many currencies, we might convert all to US dollars—a common currency. CO_2e serves as the common currency for GHGs with different values.

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[13] Alex Ballingall, "Trudeau Promises to Hit 'Net Zero' Emissions by 2050," *Toronto Star*, Sept. 24, 2019.

[14] United Nations Framework Convention on Climate Change (UNFCCC), "Adoption of the Paris Agreement" (Paris: UNFCCC, December 12, 2015), Article 2, https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Chapter 4: Agricultural Emissions

Agriculture does not produce GHG emissions, agricultural inputs produce GHG emissions.

Types, sources, and quantities of emissions

Agricultural emissions make up about 12% of total Canadian emissions.[15] Canada's farms produce three main greenhouse gases: [16]

1. Carbon dioxide (CO_2), mostly from the combustion of farm fuels; the production of the electricity used on farms; and from the production of farm inputs (fertilizers, chemicals, machinery, etc.);
2. Nitrous oxide (N_2O), mostly from nitrogen chemistry in our soils (and this mostly from the application of synthetic nitrogen fertilizer), with some contribution from manure; and
3. Methane (CH_4), mostly emitted from the mouths of cows as they digest grass, though with an added contribution from manure decomposition.

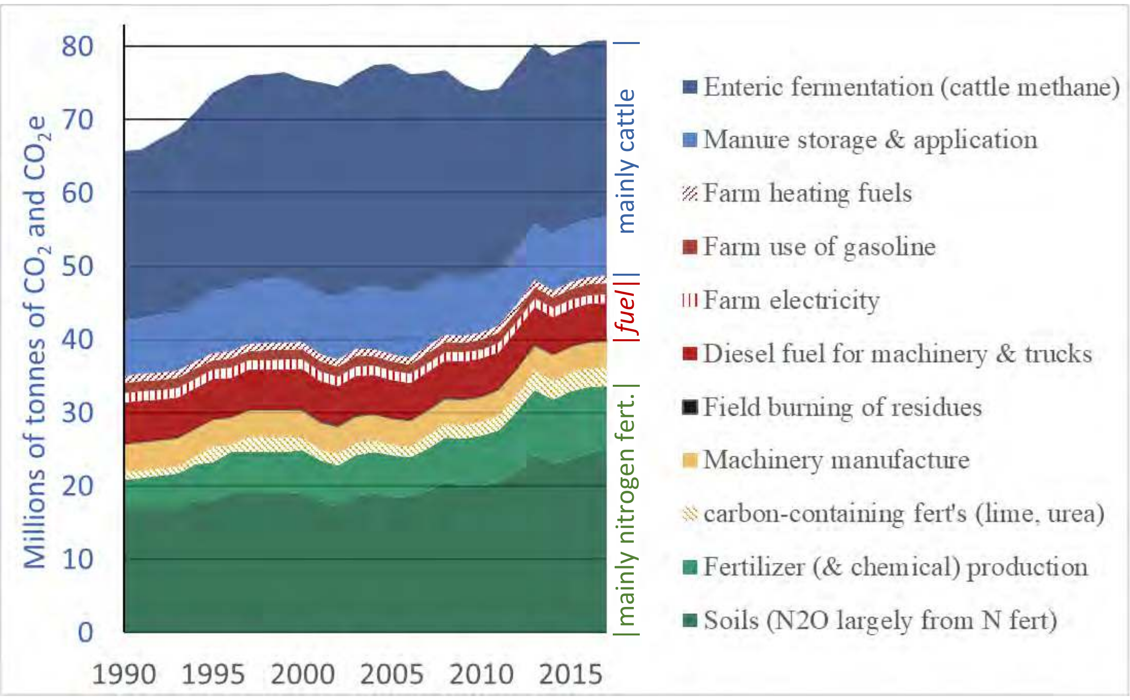

Figure 4-1. Canadian agricultural greenhouse gas emissions, 1990–2017

Sources: Environment and Climate Change Canada, "Canada's Official Greenhouse Gas Inventory"; and calculations of emissions from fuel use, electricity production, and fertilizer manufacture based on reports by Dyer et al.[17]

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[15] This percentage does not include transport of farm inputs and products by non-farm trucks or by rail. Including those emissions from transport, however, would leave the 12% figure largely unchanged.

[16] In addition to these mains sources, agricultural land use also creates emissions from the conversion of forests to farmland; the destruction of shelterbelts, bluffs, and other trees; and the destruction of wetlands. The removal of trees and wetlands is often driven by farm economics and the imperative to farm ever more land to makes ends meet. In this and other ways the challenging farm income situation contributes to rising emissions.

[17] J. Dyer et al., "Integration of Farm Fossil Fuel Use with Local Scale Assessments of Biofuel Feedstock Production in Canada," in *Efficiency and Sustainability in Biofuel Production*, Ed. Barnabas Gikonyo (New York: Apple Academic Press, 2015); J. Dyer et al., "The Fossil Energy Use and CO_2 Emissions Budget for Canadian Agriculture," in *Sustainable Energy Solutions in Agriculture* (Boca Raton: CRC Press, 2014); and J. Dyer and R. Desjardins, "Carbon Dioxide Emissions Associated with the Manufacturing of Tractors and Farm Machinery in Canada," *Biosystems Engineering* 93, no. 1 (Jan. 2006).

Figure 4-1 shows Canadian agricultural emissions over the past 28 years. [18] The units are millions of tonnes of CO_2e. Emissions are rising—up about 20% since 1990.

The graph appears complex, with eleven different categories of agricultural emissions. However, there are really just three main classes of emissions. First, the two bottom categories, in green, are largely attributable to nitrogen fertilizer. The bottom category, "Soils," is mainly made up of nitrous oxide emissions from the application of nitrogen fertilizer,[19] and the category second from the bottom, "fertilizer and chemical production," is largely made up of carbon dioxide emission from nitrogen-fertilizer manufacturing. Also included in that category are emissions from the production of other fertilizers, especially potassium and phosphorus, as well as pesticides.

The red categories in the middle—on-farm use of gasoline, electricity, heating fuels, and diesel fuel—are mainly CO_2 emissions from fossil fuel consumption.

The two blue categories at the top are attributable to livestock. "Manure storage and application" is nitrous oxide and methane emissions from wet or dry storage and application of hog, poultry, sheep, and cattle manure (pasture-dropped manure is excluded). The top category, "Enteric fermentation" is methane emitted from the mouths of ruminants when they digest grass. This category is dominated by emissions from cattle. Moreover, a portion of the emissions from the other categories could also be included under cattle and livestock, including the fuel- and fertilizer-related emissions from the production of grain for livestock feed. Indeed, it is hard to partition emissions between crop and livestock systems.

Figure 4-2, reprinted from Agriculture and Agri-Food Canada (AAFC), includes many of the emission sources described above. Starting from the left, the factories and mines producing fertilizers (nitrogen, potassium and phosphorus), pesticides, or machinery emit CO_2, as does the electrical-generation system (though these emissions would be small in provinces such as Quebec and Manitoba where much of the electricity comes from low-emission hydroelectric dams). Heating the house and powering the tractor release CO_2 as fuels are combusted. Nitrogen fertilizers and manure applied to the land give of N_2O, as does manure storage and handling and manure dropped in pastures (though this last category is not counted in Canadian inventories). Cattle give off CH_4, as does manure storage.

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[18] Notes: 1. Governments and the UN IPCC often publish agricultural-emission estimates that omit on-farm energy use (often reported under "transport") and farm-input manufacturing (reported under "industrial processes"). This report includes all ag.-related emissions. 2. Some farm inputs are produced outside Canada, and some are produced here and exported. Thus, a question: what to include in *Canadian* emissions. This report attributes to Canadian agriculture emissions equal to those that would be created to produce all farm inputs used here. It assumes that emissions associated with imported and exported inputs cancel out each other. Different assumptions would not significantly alter emission estimates.

[19] Approx. 57% of the "soils" category is attributable to nitrogen fertilizer. See Environment and Climate Change Canada, *National Inventory Report 1990-2014: Greenhouse Gas Sources and Sinks in Canada: Part 1* (Ottawa: ECCC, 2016), 121.

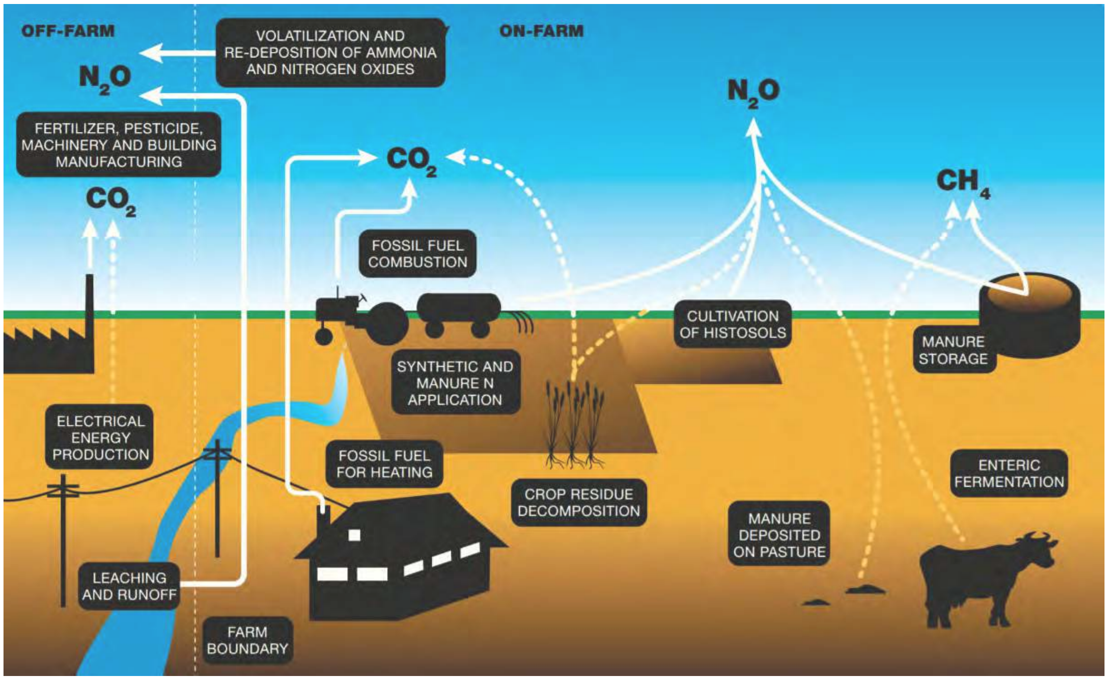

Figure 4-2. A graphic of the sources of agricultural GHG emissions
Source: Reprinted from H.H. Janzen et al., *Better Farming, Better Air: A Scientific Analysis of Farming Practice and Greenhouse Gases in Canada* (Ottawa: AAFC, 2008)

Farmers are also leading the solutions

Farmers risk becoming major victims of climate change; and, like people in nearly every sector of our economy, farmers are significant contributors to climate change; but farmers are also leading the struggle to slow and control climate change. Farmers are stewards, innovators, builders, leaders, trustees of intergenerational legacies, and men and women with deep commitments to protecting land, air, water, and animals. Virtually every Canadian farm family has already taken steps to reduce energy use and emissions. Farmers are searching for new ways to produce crops and livestock that protect the environment and the future, and when they find approaches that work, they often make significant investments.

Any observer of Canadian farms and farming practices has witnessed significant changes in recent decades. Farmers are changing the way they seed and control weeds—tilling and ploughing less, using less machinery fuel, and drawing carbon out of the air and sequestering it in soils. Farmers are changing the way they raise and graze cattle—increasing productivity, decreasing energy use and emissions, and capturing carbon. Many farmers who produce vegetables, specialty foods, honey, and other products are installing alternative energy systems to produce electricity and hot water for their operations, or they are retrofitting their buildings to make them more energy efficient. Farmers are experimenting with composting, methane-capturing digesters, and other manure-handling techniques that can increase nutrient availability and reduce emissions. And farmers are adopting high-tech monitors and precision-farming controls that optimize input use and reduce over-application.

Farmers have the power to dramatically reduce GHG emissions. Many have the will to undertake complex changes and costly investments. Many are finding that changes to reduce emissions also have other benefits. For example, carbon-building tillage and grazing techniques improve soil quality, build organic matter, improve drought resistance and water-holding capacity, aid nutrient release, and increase productivity and profitability. Organic agriculture, with its superior energy efficiency, not only reduces GHG emissions, it also protects the biodiversity of soil organisms and earns premium prices for organic producers. And investments in energy efficiency can earn significant returns and sometimes repay initial costs in a few years.

Farmers are eager to do more to help slow and limit climate change. Farmers want a lead role in formulating plans to reduce agricultural emissions. This report outlines the ways farmers can invest and innovate to make large reductions in emissions.

The true source of agricultural emissions

To reduce agricultural GHG emissions we must understand their *real* cause. To a significant extent, emissions are largely the result of farm input overuse. Here is a more provocative version of that statement: agriculture does not produce GHG emissions, agricultural *inputs* produce GHG emissions.

In Figure 4-1, the graph showing Canadian agricultural emissions, the bottom two categories of emissions—those related to nitrogen fertilizer use—are driving the overall increase. Nitrogen-related emissions increased faster than emissions overall—the upward trend in the bottom two categories is steeper than the upward trend for the top line. Overall, emissions related to the production and use of nitrogen fertilizer are up by more than 50% between 1990 and 2017.

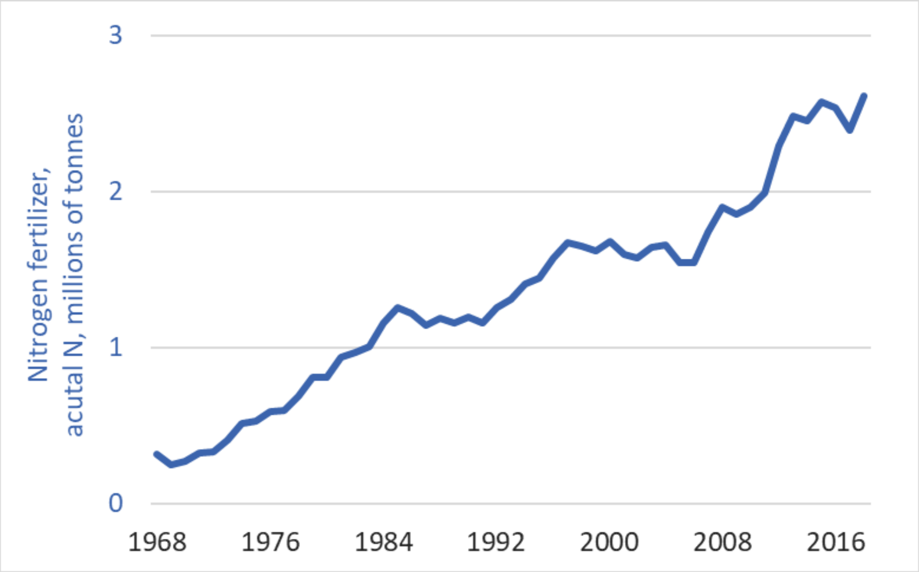

Figure 4-3. Canadian nitrogen fertilizer application tonnage, 1968–2018
Sources: Statistics Canada Table 32-10-0037-01 (001-0067); and Maurice Korol, Gina Rattray, and Agriculture and Agri-Food Canada, *Canadian Fertilizer Consumption, Shipments and Trade 1997/1998* (Ottawa: AAFC, 1999)

Figure 4-3 shows the consistent upward trendline in nitrogen fertilizer use in Canada and the doubling of tonnage since 1993. In many provinces the increase has been even more rapid. For example, in Saskatchewan, tonnage has *quadrupled* since 1991 (see Figure 7-1).

Nitrogen fertilizer is a fossil-fuel product. The cost of natural gas forms as much as 90% of the cost of making nitrogen fertilizer (ammonia).[20] A nitrogen-fertilizer factory has a large natural gas pipeline feeding into one end and a large ammonia pipe coming out the other. That ammonia is used directly or as a feedstock for granular nitrogen fertilizers. To produce, transport, and apply one tonne of nitrogen fertilizer requires energy equivalent to nearly two tonnes of gasoline.[21] Nitrogen fertilizer creates large emissions in its manufacture (mostly CO_2) and when it is applied to fields (mostly N_2O). Roughly 28% of all Canadian agricultural emissions come from the manufacture and application of nitrogen, and as we double and redouble its use, agricultural emissions rise. The more fertilizer and other inputs we push into our food systems, the more emissions we will push out.

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[20] Randy Schnepf, "Energy Use in Agriculture: Background and Issues" (Washington, DC: Congressional Research Service, The Library of Congress, 2004), 3 & 4, https://nationalaglawcenter.org/wp-content/uploads/assets/crs/RL32677.pdf .

[21] Clark Gellings and Kelly Parmenter, "Energy Efficiency in Fertilizer Production and Use," in *Efficient Use and Conservation of Energy*, in *Encyclopedia of Life Support Systems* (Oxford, UK: EOLSS Publishers, 2004), 9. It takes 78,230 kJ/kg to make, package, transport, and apply nitrogen. This energy density is just less than double the density of gasoline: 44,000 kJ/kg.

The solution to our emissions problem, and to our income problem

The direct cause-and-effect relationship between input use and emissions becomes even clearer when we look at the big picture and the long term. Humans have practiced agriculture for about 10,000 years. For 9,900 years it was low input, low-energy-use, and low emission. But for less than 100 years—for less than 1% of the time we have practiced agriculture—we have been attempting a novel experiment: we have created a high-input, high-energy-use, fossil-fuelled, *high-emission* system.

Farmers farmed for 9,900 years and GHG levels did not rise. Farming did not alter the atmosphere or the climate. Now, however, our high-input, high-energy-use system is a huge source of climate-destabilizing emissions.

Ten thousand years of history makes one thing crystal clear: farming does not create GHG emissions; petro-industrial farm inputs create GHG emissions. This radical insight leads directly to another: any low-emission food system will be a low-input food system. Our GHG emission outputs are direct consequences of our fossil-fuel-intensive farm inputs. To reduce emissions, our agricultural and food systems must be restructured—made much less dependent upon petro-industrial inputs. Our high-input food-production model has no future.

Here is another way to understand our emissions problem: During the 20th century, we broke open the circular flows of energy, fertility, seeds, etc. that were the basis of agriculture for 9,900 years. We cracked open those circular flows, stretched them out, made them linear, and found ways to push ever-increasing quantities of fuels, fertilizers, chemicals, steel, and plastic into one end, and thus force an ever-increasing tonnage of food out the other.[22] This highly productive linear-flow food system also created large outflows of GHG emissions, because those millions of tonnes of farm inputs have to go somewhere. The carbon molecules in fuels and nitrogen molecules in fertilizers cannot just disappear. Stuff megatonnes of fertilizer into our linear food-production system and it comes out the other end, into the air as greenhouse gases (N_2O) and into our waterways to create algae-choked lakes or ocean dead zones.[23] Stuff in megatonnes of carbon-based fossil fuels and they come out as carbon-dioxide emissions to destabilize the climate. Because our food systems are high-output, high-throughput, *linear* systems, nearly all the inputs we push into one end must come out the other: as emissions, runoff, by-products, landfilled waste, toxins, collateral damage, and unintended consequences. To staunch the flow of emissions from the output end of our linear food production system we must curb the quantities of fuels, fertilizer, etc. we force into the input end.

Most important to farm families, a lower-input, lower-emission agricultural system can be *a higher-net-income system*. As we find ways to produce adequate yields with less purchased nitrogen and other inputs, our costs can fall faster than our revenues. The portion of gross revenue captured by agribusiness corporations can decline and the portion retained on our farms can rise. We can return to the percentages of revenue sharing between farmers and agribusiness that were common in the 1970s and early-1980s. A low-emission future can mean a decoupling from our overdependence on purchased inputs. And that can mean freeing farmers from the profit-extracting grip of seed, chemical, fertilizer, fuel, and machinery companies.

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[22] These ideas are developed at length in: Darrin Qualman, *Civilization Critical: Energy, Food, Nature, and the Future* (Black Point, NS: Fernwood Publishing, 2019).

[23] Dead zones, usually found where rivers empty into oceans, are caused by nitrogen runoff. Worldwide, more than 500 ocean dead zones now cover hundreds of thousands of square kilometres. See, for example, Robert Diaz and Rutger Rosenberg, “Spreading Dead Zones and Consequences for Marine Environments,” *Science* 321. That report notes that: “declines in [dissolved oxygen levels] have lagged about 10 years behind the increased use of industrially produced nitrogen fertilizer, … with explosive growth in the 1960s to 1970s…. The number of dead zones has approximately doubled each decade since the 1960s.”

No clear-thinking person underestimates the challenges and the upheavals ahead. But climate change and the need to decarbonize opens a door. That door can lead to a future wherein farm families are more numerous and prosperous, and wherein our food supply is more secure and sustainable.

Two things happen when farmers become overdependent on petro-industrial inputs: emissions go up, and incomes go down. Easing the climate crisis by lowering input use and emissions can also go a long way toward easing the farm income crisis. Currently, farmers' net income dollars are going up in smoke.

A very challenging transition ahead

The National Farmers Union is an organization of farm families. Our democratically elected leaders are farmers. Thus, we understand that farmers will be concerned by the uncertainty and change forced upon us by climate change. In the near future, farmers will have to figure out how to remain productive and profitable even as we reduce our use of purchased inputs. At the same time, we will face increasingly hostile weather. We will be asked to make major investments in energy efficiency and emission-reduction measures even as overseas markets become less dependable and crop yields and forage production become more variable. We will face new federal and provincial government policies and programs, probably even new taxes, with unknown effects on our revenues and net incomes. As a nation we face profound and disruptive change in our energy and food systems, and in all parts of our society and economy. These are anxious times for Canada's farm families.

However, we also have a tremendous opportunity—an opportunity that comes perhaps only once in many generations: to re-imagine and restructure our farming and food systems. This is good news. Because the economic and food-production systems that have damaged the climate have also damaged our family farms. If we continue for another generation along the path we are now following the family farm may not survive as a relevant entity in Canada. The family farm may go the way of the family-owned movie theatre, shoe store, grocery store, or hardware store. The corporate-controlled, input-maximizing food production systems that are destabilizing our climate are destroying our family farms. To cling to the current system is folly. Climate change is a crisis, and because this crisis forces upon us wholesale change, we can leverage that change for our benefit.

Farmers can change. We've done it before. We've made huge changes. Imagine a farm in 1900. No electricity, phone, trucks, tractors, fuels, fertilizers, or chemicals. Now imagine that same farm in 1950. The change is breathtaking. In the first half of the 20th century, fossil fuels transformed agriculture. In the first half of the 21st century, the project to slash fossil fuel use and GHG emissions will transform agriculture again. In the first half of the 20th century Canadians and citizens of many nations replaced solar-powered, zero-net-emission farming systems with fossil-fuelled, high-input, high-emission systems. In the first half of the 21st century we must largely accomplish the reverse. And as we undertake this transformation we can build the farms and food systems Canadian citizens and farm families want—with more farmers on the land, especially young farmers; a rich diversity of delicious regional food; sustainable incomes for all who help produce and process our foods; and diverse, environmentally sustainable approaches to stewarding the land and raising safe, nutritious food. Climate change makes it necessary to cut agricultural greenhouse gas emissions, but climate change also creates the opportunity for a transformation of our farms, tables, communities, and landscapes.

Climate change is a threat to farm families. But measures to reduce emissions need not be a threat. A transformation of agriculture that reduces emissions, energy use, and input-overdependence can increase net farm incomes, levels of soil organic matter, fertility, biodiversity, water quality, the number of farmers on the land, and employment in our food system. A low-emission future can be a better future for farm families and for workers and other citizens of Canada.

Chapter 5: A Plan to Reduce Emissions

On-farm measures and government policies aimed at reducing GHG emissions can be part of a larger transformation of agriculture that will lead to higher net farm incomes, more farmers, and a more prosperous and stable rural Canada.

The physics of the planet and its atmosphere forces upon our global civilization the need for sweeping, rapid change to all our systems of manufacturing, settlement and housing, transportation, communication, energy supply, and food production. Farmers have just two options: we can act rapidly and collectively to create a set of plans that put our needs and interests at the forefront of discussions of food-system transformation; or we can deny and delay and engage in wishful thinking and thereby forfeit the task of defining our future to others—to distant governments, non-farmer bureaucrats, academics, and agribusiness executives. Farmers need to lead; we need a plan.

This report sketches such a plan. It looks at how we might achieve a 30% reduction in Canada's agricultural emissions by 2030 and perhaps a 50% reduction by 2050. This report takes a *systematic* view of agriculture—respecting how the many aspects of food production interconnect. It offers an *integrated* plan that includes recommendations for on-farm *measures* and government *policies*. Our recommendations for measures and policies are informed by extensive research, evidence, and science. Taken as a package, these production measures and supportive government policies can enable us to meet our national and international commitments to reduce GHG emissions, stabilize the climate, and protect Canada's farmers and other citizens from the ravages of rapid, uncontrolled global warming and climate change.

This report, however, is not some narrow, reductionist recipe to curtail the emission of certain gases. Farming is an integrated system. Farm families have many goals, including financial security, intergenerational transfer, social justice, supporting their neighbours and communities, safeguarding a beautiful and healthy environment, stewarding the soils and livestock under their care, and producing nutritious, delicious foods. Equally true, farming is *a business*—embedded in food production, processing, retailing, and trade systems in an increasingly globalized economy. Every aspect of agriculture connects with every other, and with the larger social, environmental, and economic spheres. Farming is a *system*, and its transformation to a lower-emission model must be planned and implemented in a systematic way. Narrowly focusing on a few numbers—be they emissions tonnage, crop yields, or export volumes—risks deforming our food-production and land-stewardship systems.

That said, two categories of actions are needed to reduce agricultural emissions by 50% by mid-century: a suite of on-farm *measures* (e.g., more efficient and effective use of fertilizer) and new and transformed government *policies* that support and speed the proliferation of these on-farm measures. It is not always possible or desirable to stipulate every needed government policy. While this report sometimes recommends specific policies, at other times it points to the needed outcome (e.g., increased farmer access to independent soil testing) and does not detail the many regulatory and policy changes and public investments required. This does not, however, mean that governments need not act. Quite the opposite is required: Governments must lead a near-wartime level of action and mobilization. It is simply impossible (and probably tedious) to list every government policy change needed over the next three decades. We expect that responsible governments will develop robust internal capacities to identify needed policies and act quickly to implement them.

The following chapters form the foundation of a plan to safeguard farmers, food production, the climate, and the future.

The main emission sources

As noted, there are three main sources of agricultural emissions:

1. From fuel combustion (diesel fuel, gasoline, and natural gas for heating) and from the production of electricity using fossil fuels. These sources make up about 11% of Canadian agricultural emissions.

2. From agricultural soils (mainly a result of nitrogen fertilizer production and use). Nitrogen production contributes about 11%, and emission from fertilizer use make up about 18%, for a total of 29% of agricultural emissions.

3. From cattle ("enteric" methane from their mouths; a by-product of microbial digestion of grass). Emissions from livestock—both enteric methane and emissions from manure storage and application—make up more than 30% of agricultural emissions.

Together these three categories account for about 70% of total agricultural emissions. This is where our reduction efforts must focus.

Solutions, in general[24]

Certain general observations regarding how to reduce GHG emissions can lay the groundwork for more specific recommendations. Our general recommendations include:

Electrify everything possible because electricity can be decarbonized. Hydroelectric dams, wind turbines, and solar panels can produce electrical power with few emissions. As widely and rapidly as possible, we need to replace fossil-fuelled engines, furnaces, etc. with electrically powered alternatives. In the near term, this can mean electric water heating. In the medium term, as carbon taxes and natural gas prices rise, electric heating of homes and farm shops may become cost-competitive, especially if we can also retrofit those homes and shops to lower heating requirements. Small and medium-sized tractors and light trucks can also be electrified. In Paris in 2015, Canada agreed to reach net-zero emissions in the second half of this century.[25] In late-2019, Prime Minister Trudeau pledged that Canada would be carbon neutral by 2050. Emission-reduction programs of this magnitude make the adoption of electric heating, electric vehicles, and electric tractors *inevitable*. And the long service-lives of many types of farm equipment means that non-emitting versions must be made available soon if large numbers are to be in place in a decade or two.

Emission-reduction measures must rely on existing technologies. To reduce emission by 30% in just 10 years we must begin right now. As Stephen Pacala and Robert Socolow state in an article on how to approach emissions reduction: "It is important not to become beguiled by the possibility of revolutionary technology. Humanity can solve the carbon and climate problem . . . simply by scaling up what we already know how to do."[26] Because we have delayed for decades, the speed at which we now must reduce emissions leaves no time to search for, discover, develop, test, optimize, commercialize, and proliferate new innovations. Emissions cuts must come from proven, commercially available technologies. We need not reject new technologies, but neither should we wait for them. Nor should we be distracted by the parade of

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[24] Admittedly, there are no "solutions" to climate change, only responses.

[25] The language of the Paris agreement is that the parties agree to "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century…" United Nations Framework Convention on Climate Change (UNFCCC), "Adoption of the Paris Agreement" (Paris: UNFCCC, Dec. 2015), Article 4.

[26] S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science* 305, no. 5686 (2004), p. 968.

whiz-bang technologies-de-jour: solar shingles, algae fuels, pneumatic-tube trains. We lack will and leadership, not technological options.

Focus on emissions from nitrogen fertilizer, cattle, and fuel use. Nitrous oxide emissions from soils (about 57% attributable to nitrogen fertilizer[27]), carbon dioxide emissions from farm input production (again, mostly from nitrogen fertilizer), and enteric emissions from livestock (most of this from cattle) make up two-thirds to three-quarters of all agricultural emissions. Emissions from machinery manufacturing and on-farm fuel use make up much of the rest. To meet our targets, we must reduce emissions related to fertilizer, cattle, and machinery production and operation.

Beware of false solutions. We must look far ahead in time to ensure that we know where we are going so that we can ensure we set out in the right direction and do not get urged down the wrong path or into a dead end. It would be disastrous to dissipate farm families' energies, good will, and scarce investment dollars into plans and purchases that are ineffective or that must be reversed or redirected in the future. It is therefore critical to understand that agribusiness corporations will promote false, self-serving "solutions" that maximize input purchases and their own profits rather than minimizing emissions. We should invest only in measures that can carry us through to the very ambitious GHG-reduction targets we must ultimately achieve. We must ensure that the emission-reduction steps we take today lay the groundwork for the transformed food systems we will need tomorrow.

Distinguish between soil carbon sequestration and emissions reduction. It is critical that we improve the health of our soils and increase levels of carbon and organic matter. High-carbon soils are black, alive, rich-smelling, and full of beneficial fungi and other organisms. Higher soil carbon levels help crops withstand drought (reducing the need for energy-intensive irrigation), reduce the need for synthetic fertilizers (again reducing emissions), and perhaps even help reduce the need for fungicides, herbicides, and insecticides. Our cropping and grazing methods must increase soil carbon levels. But we should not become confused by claims that we can somehow fix the climate crisis by pulling carbon out of the atmosphere and "sequestering" it in soils. This is a false solution for many reasons. Appendix B details the realities and limits of soil carbon sequestration. Four points can be noted here:

1. Soil-sequestered carbon can be released. Just as positive changes in production practices can sequester soil carbon, other changes in practices can release it, and so can increased temperatures or decreased rainfall—ominous news as climate change intensifies.

2. Soil carbon levels are difficult and expensive to measure, requiring many samples over many years. There exists no simple, inexpensive system to verify soil carbon changes over Canada's tens-of-millions of acres.

3. In calculating national emission levels and Canada's success in reaching its Paris targets, the UN and other emission-accounting bodies will not count overall sequestration; they will only count *increases* (if any) in the *rate* of soil carbon sequestration *over and above* the relatively high rates that existed in 2005, our reference year. For the most part, sequestration won't count.

4. Most important, *soil carbon sequestration occurs only for a limited time*, perhaps two to four decades. After that, sequestration slows or stops as soils become "saturated" and a new equilibrium is reached between the rate at which carbon is added (via plant biomass, root exudates, etc.) and the rate at which soil microorganisms consume organic matter and release carbon as CO_2. Seen another way: the maximum amount of soil carbon that farmers can sequester via enhanced management is roughly equal

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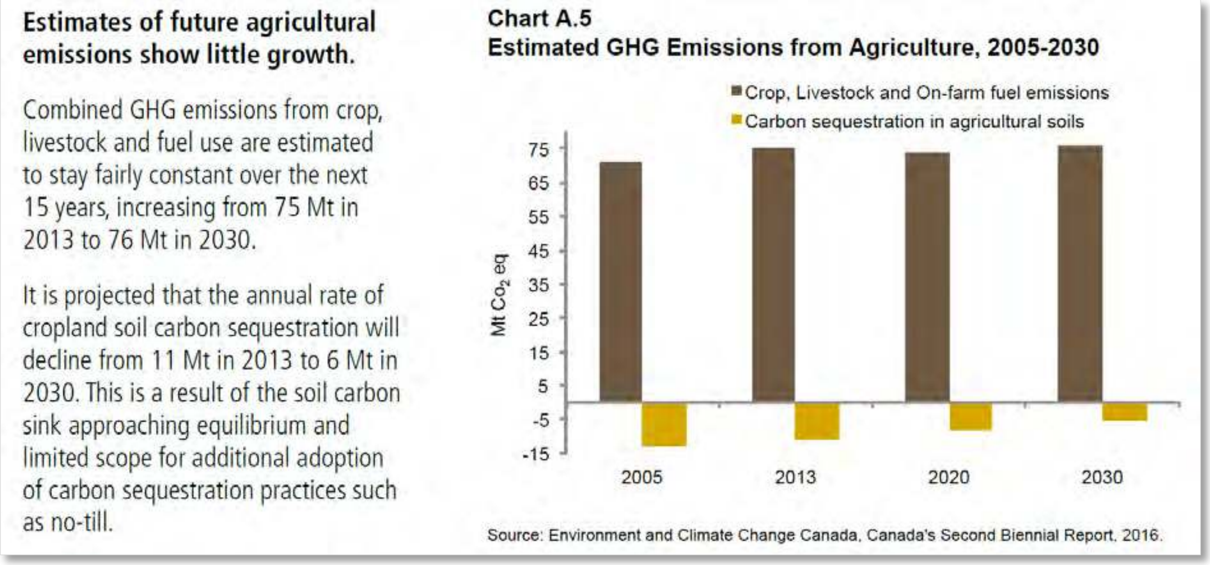
[27] Environment and Climate Change Canada, "National Inventory Report 1990-2014: Greenhouse Gas Sources and Sinks in Canada: Part 1," Table 5-1, 121.

> to the amount released previously due to sub-optimal management. What we call "sequestering" carbon is, in many cases, the return of carbon that previous farming practice released. ***It is hard to raise soil carbon levels above those that existed at the time of initial European settlement. In western Canada, for example, the soil carbon content at that time was the result of more than 10,000 years of bison rotationally grazing on untilled, deep-rooted grasslands.*** No matter how sophisticated our cropping or grazing techniques, at some point soil carbon content reaches a limit—a limit we might call the "bison prairie maximum."

Figure 5-1 is a screen capture from a 2016 report by Agriculture and Agri-Food Canada (AAFC). That report states that "it is projected that the annual rate of cropland soil carbon sequestration will decline from 11 [million tonnes per year] in 2013 to 6 Mt in 2030. *This is a result of the soil carbon sink approaching equilibrium* and limited scope for additional adoption of carbon sequestration practices such as no-till" [italics added]. AAFC is clear: high rates of carbon sequestration last only for a few decades, and those rates are already declining.



Estimates of future agricultural emissions show little growth.

Combined GHG emissions from crop, livestock and fuel use are estimated to stay fairly constant over the next 15 years, increasing from 75 Mt in 2013 to 76 Mt in 2030.

It is projected that the annual rate of cropland soil carbon sequestration will decline from 11 Mt in 2013 to 6 Mt in 2030. This is a result of the soil carbon sink approaching equilibrium and limited scope for additional adoption of carbon sequestration practices such as no-till.

Chart A.5
Estimated GHG Emissions from Agriculture, 2005-2030

Source: Environment and Climate Change Canada, Canada's Second Biennial Report, 2016.

Figure 5-1. Canadian cropping system emissions and soil carbon sequestration, 2005–2030
Source: Agriculture and Agri-Food Canada, *An Overview of the Canadian Agriculture and Agri-Food System* (Ottawa: AAFC, 2016)

This reality-check regarding the limits of soil carbon sequestration makes clear that, for example, choosing zero-till cropping as a climate change solution would be misguided and ill-timed. Counting (short-term and limited) sequestration as an offset to (long-term and essentially unlimited) input-related emissions *would set us off on the wrong path*.

For these reasons and others (see Appendix B) we cannot simply count soil carbon sequestration as an offset against GHG emissions and net out the two. We must think of soil carbon sequestration as different from, and separate from, emissions reduction. Increasing soil carbon levels is a soil-health bonanza, but it is not an emissions-reduction strategy or climate-change solution.

A survey of possible agricultural emission-reduction options

Building on our discussion of solutions in general, the picture becomes clearer if we divide our many options into four categories. There are four main things farmers and policymakers can do in the near- and medium-term. The options below encompass about three-quarters of emission reduction and sequestration/mitigation potentials. The NFU is not advocating all these options—our recommendations come next. Rather, we begin by cataloguing and categorizing most of the available measures. **To be clear, this is a "long list" of possible actions, not a list of NFU recommendations.**

1. Reduce carbon dioxide (CO_2) emissions from energy use by:
   - improving the energy efficiency of factories producing fertilizers, pesticides, machinery, and other inputs; and, later, by switching these factories to low-emission energy supplies such as hydroelectricity or solar- or wind-generated electricity; then possibly by reducing their emissions further with carbon capture and storage (CCS);
   - reducing production and use of fertilizer and other emissions-intensive inputs;
   - reducing grain, livestock, and food transport distances and maximizing the use of trains and other energy-efficient carriers;
   - improving the energy efficiency of buildings, lighting, pumps, refrigeration, etc.;
   - replacing fossil fuels with electricity: electric space heating and water heating, battery-electric smaller tractors and light trucks, electrically powered trains, and perhaps, more speculatively, hydrogen fuel for large machinery.
   - utilizing solar-thermal water heating and passive solar space heating;
   - speeding deployment of renewable energy production, especially solar and wind—focusing equally on large utility-scale facilities and on-farm solar arrays.
2. Reduce nitrous oxide (N_2O) emissions from land and manure by:
   - reducing emissions from a given quantity nitrogen fertilizer (e.g., by utilizing coated granules, better placement, proper timing, and all 4R best management practices[28]);
   - reducing the amount of synthetic nitrogen fertilizer required (e.g., by including legumes or perennials in rotations);
   - using precision-farming technologies to reduce/optimize fertilizer application;
   - increasing the use of organic, integrated, agroecological, and other low-input cropping systems;
   - minimizing emissions from manure application.
3. Reduce methane (CH_4) emissions from ruminant livestock by:
   - reducing emissions from each animal (e.g., maximize feed digestibility, etc.);
   - exploring the (currently unproven) potential of methane-suppressing feed additives;
   - holding beef production constant but reducing the *number* of cattle needed to produce that quantity of beef, via better herd health, improved genetics, more aggressive culling, etc. (i.e., making production more "efficient");
   - reducing beef production;
   - reducing emissions caused by manure handling and storage;
   - capturing methane from manure to produce heat or electricity;
4. Sequester carbon in soils by:
   - enhancing grazing management and improving pastures (legumes, adaptive multi-paddock or rotational grazing, etc.);
   - using a different mix of annual crops, rotations that include perennial crops, intercropping, or cover crops;
   - reducing tillage in cropping systems;
   - utilizing enhanced production systems or approaches such as agroecology, organic farming, and holistic management;

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[28] The 4R BMPs include using the right fertilizer, at the right time, in the right quantities, and putting it in the right place.

- stopping the ***de***sequestration of carbon by stopping the destruction of wetlands, shelterbelts, tree bluffs, and forests.

This list makes our options more understandable. However, in developing any plans, we must remain vigilant for linkages and interactions between the various parts within farm *systems*. If we do not think about farming as a whole, we risk overlooking trade-offs and we risk unintended consequences. For example, research shows that farmers can increase soil carbon and reduce nitrous oxide emissions by adding alfalfa or other perennial crops into their annual-crop rotations.[29] But if this practice is widely adopted the supply of alfalfa will increase. This increase in supply could reduce the price of alfalfa, eroding the economics of including that perennial in crop rotations. Alternatively, increased alfalfa production could spur an expansion of the cattle herd, and this could lead to *increased* enteric methane emissions from that expanded herd. *Conversely*, reducing cattle numbers may cause farmers to break up hay- and pastureland and begin cropping it, releasing soil carbon as carbon dioxide, and releasing nitrogen from fertilizer as nitrous oxide. Every on-farm emission-reduction measure interacts with every other measure, and with other financial, ecological, and social factors. In this report we look at the system as a whole and evaluate a suite of emission-reduction measures in relation to each other, so we can identify and evaluate those interactions.

Our farms and food systems are complex *systems*. Transforming them and reducing their emissions must be done in a systematic way. Reductionism, half-measures, and the easy solutions offered up by agribusiness corporations and less ambitious farm organizations will only lead us down the wrong path, or slow our progress on the right one.

The following chapters present the NFU's recommendations for on-farm GHG emission reduction measures and supportive government policies that can, as a package, reduce Canada's agricultural emissions by approximately 30% by 2030 and perhaps by 50% by 2050. Moreover, these measures and policies can be part of a larger transformation of agriculture that will lead to higher net farm incomes, more farmers, and a more prosperous and stable rural Canada.

As noted, the emission-reduction priorities are fuel use in farm machinery and buildings; emissions from nitrogen fertilizer and other inputs; and emissions from livestock, mainly cattle. This report proceeds in that order.

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[29] Alison J. Eagle et al., "Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature," 3rd Ed. (Durham, NC: Duke University, The Nicholas Institute for Environmental Policy Solutions, 2012), 15, https://nicholasinstitute.duke.edu/ecosystem/land/TAGGDLitRev .

Chapter 6: Reducing Emissions from Machinery and On-Farm Energy Use

By phasing in a number of measures and technologies machinery emissions could be cut by more than half. We can also reduce emissions from farm buildings.

Reducing emissions: Diesel tractors

Phase 1: Starting immediately, emissions reductions can result from operating the existing fleet of tractors and other equipment more efficiently and with minimal slippage. Many tractors incur efficiency penalties because they are improperly weighted; their tires are worn; they are operated at the wrong RPM or in the wrong gear; or their fuel systems need servicing.

Phase 2: Design new tractors to maximize fuel efficiency and minimize slippage. Measures could include incentivizing best-performing tires or tracks; use of guidance systems to minimize overlap; and monitors that display emissions per acre—making farmers aware of how changes in loading, gearing, and slippage affect emissions, fuel use, and costs. The Prairie Agricultural Machinery Institute (PAMI) could lead.

Phase 3: Replace 50% of the diesel fuel used in farm machinery and trucks with biofuels—from locally-grown oilseeds crushed at regional, co-operatively-owned plants. Such fuel will not be near-zero emission because oilseed production utilizes emissions-producing fertilizers, fuels, etc. Nonetheless, replacing half of farm diesel fuel with oilseed-sourced fuels may cut machinery-related GHG emissions by about 20%. And as oilseed production becomes less fossil-fuel-intensive, associated emissions will fall. Roughly 5% of Canada's cropland will be required to produce enough fuel to supply 50% of farm needs.[30] The NFU does not support biofuels in general, and biofuel programs should not be scaled up to serve the automobile fleet. But in certain cases, targeted use may reduce emissions on a limited-time, interim basis until new technologies can be made available. On the other hand, we can avoid the interim step of biofuel use altogether if farmers move to rapidly adopt electric tractors (see next section).

Action	**On the existing tractor fleet, optimize weighting, replace worn tires, and minimize slippage; on all machinery tune engines and fuel systems; hold clinics on strategies to reduce fuel use, costs, and emissions.**
Action	**Design new tractors to minimize emissions by using enhanced traction technologies; and include monitors to help operators understand emissions and energy use.**
Action	**Replace half of current diesel fuel use with fuels from locally sourced oilseed crops**
GHG Savings	15 to 25% of emissions from tractor and machinery use
Costs	Higher costs for fuels, new tires, and for new machinery
Co-benefits	Lower fuel use, local energy production, less price volatility, avoidance of carbon taxes.
Problems	Using food land to produce agricultural fuels; fuel compatibility with some tractors.
Start	Begin in 2020.
Completed	2030.

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[30] Assumptions: 50% of total ag fuel use is 1.5 billion litres; canola yields 0.8 tonnes per acre; oil extraction efficiency is 90%; oil content of canola is 43%. Approximately 4.5 million acres would be needed out of a total cropland area of 95 million acres.

Reducing emissions: Electric tractors!

As a fourth phase, and in parallel with addressing diesel tractors, machinery companies, research organizations, and governments must develop battery-electric farm equipment. Many smaller and medium-sized tractors (<150 HP) could potentially be replaced by battery-electric models using off-the-shelf technologies like those from automakers Tesla, GM, and others. By modifying existing components, it should be possible to build an 80 or 120 HP tractor that could run for 5 to 10 hours on a charge and that could recharge to 80% capacity in 1 to 2 hours, thus making full-day operation possible. Battery-electric tractors would be quiet and smooth and have fewer moving parts, potentially longer service lives, lower maintenance costs, and could be operated inside barns and enclosed spaces. John Deere and Fendt have demonstrated prototypes, though high-horsepower run-time remains a limitation.

In several provinces (e.g., Manitoba, British Columbia, and Quebec) the electricity supply is near-zero emission thanks to abundant hydroelectricity. In those provinces electric tractors would produce very low emissions during operation. And as other provinces “green” their energy supplies or farmers install their own solar arrays, emissions from electric vehicles and machinery will also fall in those places.

Canada could become a leader in electric-tractor production. Take Manitoba as an example. Winnipeg is home to the New Flyer bus company, which makes battery-electric buses, and is also home to tractor-maker Buhler-Versatile. A consortium involving those two companies, Manitoba Hydro, and provincial and federal governments could soon yield Manitoba’s first electric tractors and help make the province a world leader in the manufacture of low-emission farm equipment. In so doing, Manitoba could create jobs, develop new technologies, localize food-production energy sources, protect farmers from volatile energy prices, and remove the need to pay carbon taxes on the energy that powers farm machinery. Other provinces could implement similar plans. The climate crisis and the need to retool agriculture creates the opportunity for a Canadian farm equipment manufacturing renaissance.

Action	**Develop lower-emission battery-electric tractors and machinery.**
GHG Savings	80% of emissions from tractor operation in provinces that have low-emission electricity sources (e.g., Quebec or Manitoba), in most provinces once renewable energy is deployed more widely, and on any farm generating its own electricity from renewable sources.
Costs	Prices of electric cars are declining and may soon match prices of non-electric. A similar phenomenon may play out for tractors. Electricity from clean sources will become less expensive relative to fossil fuels as carbon taxes rise. Lifetime purchase, maintenance, and operating costs may be lower for electric machinery.
Co-benefits	Simple drivetrain, fewer moving parts, lower maintenance costs, and longer life.
Problems	Weight, range, and run-time limits in some cases.
Start	Prototypes in fields in the early 2020s, wide availability in the latter 2020s.
Completed	Long service lives mean complete changeover will require decades. Nonetheless, most <150 HP tractors could be electric in the 2050s.

Reducing emissions: Hydrogen-powered tractors?

A fifth phase of machinery development may include hydrogen-powered tractors at some point, though these technologies are unproven and perhaps speculative at this time. For tractors above a certain size and horsepower, batteries may become too large and heavy. For instance, to power a 300 horsepower tractor for 6 hours may require 20 times more batteries than are contained in a battery-electric car.[31] Hydrogen could be an alternative energy carrier, but hydrogen technologies and distribution systems remain problematic. Hydrogen-powered farm equipment is an option that needs more study.

Photo credits: Smithsonian National Museum of American History, “Allis-Chalmers Fuel Cell Tractor,” americanhistory.si.edu/collections/search/object/nmah_687671; Wikipedia, “New Holland NH²,” it.wikipedia.org/wiki/New_Holland_NH%C2%B2#/media/File:New_Holland_NH2_hydrogen_tractor_at_Agritechnica_2009.jpg

It is important to note that fuel cell tractor technology is not wholly new. In 1959, Allis-Chalmers demonstrated a fuel-cell powered tractor (those fuel cells were energized by natural gas, not hydrogen, though it is likely that the latter fuel would also have worked). Fifty years later, in 2009, New Holland debuted its prototype hydrogen-powered fuel-cell tractor, the NH$_2$. Toyota sells a hydrogen-fuel-cell car: the Mirai. Hydrogen-powered buses are on North American streets (though it appears that battery-electric buses may eclipse this technology in the transit sector).

Hydrogen technologies do create challenges, including producing, compressing, storing, and delivering the fuel. Hydrogen’s very low density means that it must be compressed to high pressures to fit useful amounts into relatively small spaces such as fuel tanks. Hydrogen is also expensive: perhaps double the price of diesel fuel.[32] Part of that high price may be because hydrogen remains a niche fuel. If production and distribution are scaled up, prices may fall. At the same time, diesel prices will rise as a result of carbon taxes. Over time, the cost differential between purchasing and operating a hydrogen-powered tractor vs. a fossil-fuelled tractor may converge, though to what extent is speculative.

Action	**Prototype and test hydrogen-powered machinery.**
GHG Savings	Potentially 80% of emissions from tractor operations if hydrogen is produced using low-emission electricity sources.
Costs	Difficult to predict because of unknown fuel costs and fuel-delivery challenges.
Co-benefits	Fewer moving parts. Perhaps longer machinery life. Perhaps lower maintenance costs.
Problems	Several. See above.
Start	Uncertain. First production units in the early 2030s?
Completed	Uncertain. Depends on long-term performance and economics.

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[31] This rough calculation assumes 30 HP is needed to sustain highway speeds in an electric car and that the car can maintain such speeds for 3 hours. Thus, a tractor requires 10 times more HP and 2 times the duration—20 times more battery capacity.

[32] Jonny Wakefield, “B.C. Transit Quietly Sells off Hydrogen Buses,” UBC Sauder School of Business, Dec. 11, 2014.

Reducing emissions: Lights, pumps, and heating

Installing highest-efficiency lights, pumps, refrigeration units, and other electrical devices will save farmers money on energy bills. It will also reduce emissions in provinces that do not have low-emission electricity. (BC, Manitoba, and Quebec have low-emission supplies based mainly on hydroelectric power; increasing the efficiency of electrical devices in those provinces will not reduce emissions.)

Action	**Speed the installation of high-efficiency lights, pumps, refrigeration units, etc.**
GHG Savings	To be determined. Detailed studies will be needed.
Costs	To be determined. For many devices, such as lighting, savings soon exceed costs.
Co-benefits	Quieter, more comfortable homes and buildings.
Start	2020
Completed	2025

In addition, the following measures can reduce emissions of farms served by low-emission electricity systems—either their own or from low-emission provincial supplies.

1. Switch natural-gas-fuelled water heaters, clothes dryers, and stoves to electricity. Solar-thermal water heating is another option.
2. Phase in building codes to require increased energy efficiency and solar-heat harvesting in all new buildings. Codes could require homes, workshops, and processing facilities to be built to high standards: Passive House, Net Zero, LEED, or comparable. Well-insulated passive-solar structures can remain tens-of-degrees above outdoor temperatures in the winter, without heaters or furnaces. Well-designed shading and heat-repelling materials can keep buildings cool in summer.
3. Use incentives (especially zero-interest loans repayable on utility or tax bills) to dramatically accelerate the pace of retrofitting older homes and buildings to conserve energy, reduce heating requirements, save farmers money, and make feasible a switch to electric heat. (See next.)
4. Incentivize a switch to electric heat. As carbon taxes rise and buildings become more energy efficient the cost of using electricity for heat will decline relative to the cost of natural gas. Some provinces already have a high proportion of low-emission electric space-heating. In Quebec, 85% of homes are heated with electricity (from hydroelectric sources), as are 71% in Newfoundland and 66% in New Brunswick.[33] Other provinces lag. In BC and Manitoba the potential exists to switch about two-thirds of farm homes to low-emission electric heat.

Action	**Switch farm water heaters and appliances to electricity.**
Action	**Increase building standards for new homes and buildings.**
Action	**Finance energy efficiency retrofits for existing homes and buildings.**
Action	**Replace fossil-fuels with electricity for heating.**
GHG Savings	50 to 80% of building emissions.
Costs	To be determined. In many cases long-term savings will exceed costs. But energy retrofit costs remain high, necessitating financing programs.
Co-benefits	Warmer, quieter, brighter, more comfortable homes and farm buildings
Problems	High costs of retrofitting existing buildings
Start	2020.
Completed	Building codes by 2022. Retrofits & heating-system replacements in the 2020s & ’30s.

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[33] Statistics Canada, “Households and the Environment: Energy Use: 2011” (Ottawa: Statistics Canada, 2013), 19.

Reducing emissions: On-farm generation of renewable energy

Many farm families would like to produce clean, renewable power on their farms. Government policies can make a big difference to the pace at which farmers install renewable-energy systems. Figure 6-1 shows the percentage of farms that have invested in renewable energy systems—mostly solar arrays. Note the high percentages in Ontario, where generous programs encouraged farmers to become energy producers. In contrast, the Prairies have less-supportive government policies so renewable-energy systems are much less numerous, despite tremendous sunlight resources. Progressive government and utility-company policies are key to the broad-based installation of alternative energy systems.

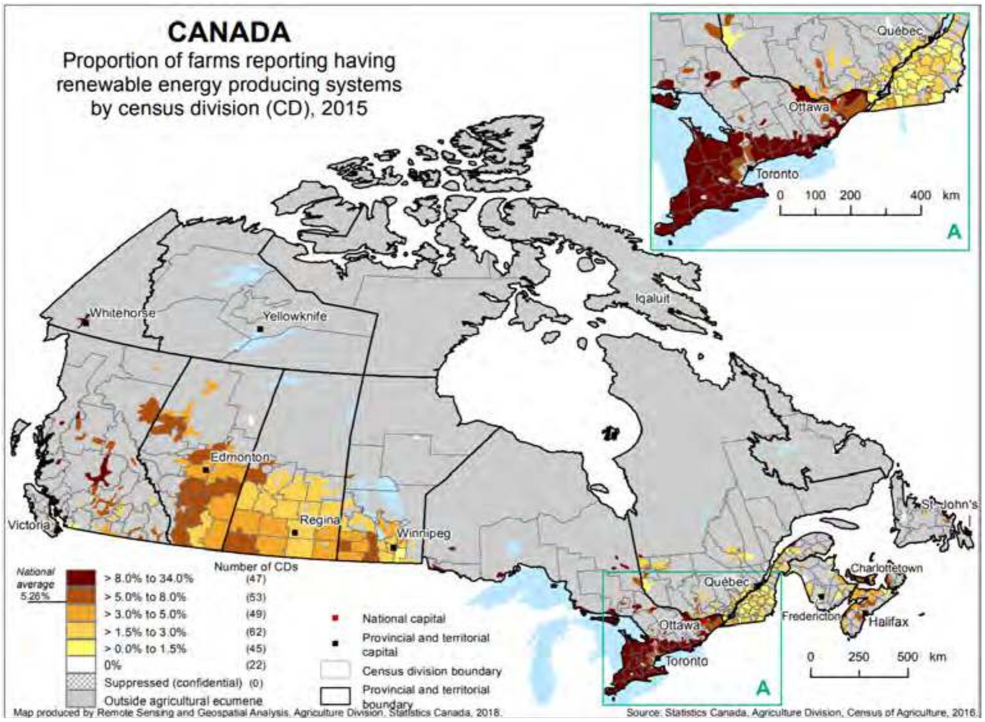

Figure 6-1. Portion of Canadian farms reporting renewable energy systems, 2015
Source: Stats. Can., "Proportion of farms reporting having renewable energy producing systems by census division, 2015 Canada," https://www150.statcan.gc.ca/n1/pub/95-634-x/2017001/article/54903/catm-ctra-364-eng.htm

In addition to small- and medium-scale, grid-tied solar arrays, farms and rural areas can also host large-scale, locally- and co-operatively-owned wind-power facilities. Some farms can produce electricity from manure, using biodigesters and methane capture. On-farm electricity generation can be combined with storage, giving emergency back-up power for the household and farm operations. And dairy and other farms that use large volumes of hot water can install solar-thermal water-heating systems. Farms and rural areas are key to creating the low-emission, decentralized, flexible, and robust energy systems we need now.

Action	**Maximize on-farm renewable energy production.**
GHG Savings	Significant, depending on the scale, ambition, & pace of decarbonizing grid electricity.
Costs	To be determined. In most cases savings match or exceed costs.
Co-benefits	Decentralized power, avoiding carbon taxes.
Problems	Unpredictability and non-dispatchability of solar energy.
Start	Ongoing.
Completed	Ongoing.

Chapter 7: Low-Input, Low-Emission Crop Production

Any low-emission food system will be a low-input food system.

Cropping systems: No-till agriculture and nitrogen fertilizer

One step forward in dealing with climate change…

One oft-cited way to reduce emissions is the increased use of no-till production methods[34]—also called "minimum-till" or "direct seeding." No-till systems have well-documented benefits relative to systems that utilize tillage and soil-disturbing seeding implements. No-till methods create a protective mulch on the soil surface, increase soil carbon levels, reduce erosion, conserve moisture, and, aided by fertilizers and other inputs, increase yields. In most cases, no-till methods are superior to approaches that rely on ploughs, cultivators, discers, high-disturbance seeding implements, or summer fallow. (Although in wetter soils, such as parts of Manitoba or Ontario, no-till agriculture may not be the best approach.)

In terms of climate-change mitigation, most of the benefit of no-till agriculture comes in the form of soil carbon *sequestration*. But no-till agriculture can also bring *emissions reductions*, largely from reduced fuel combustion. In some no-till systems, large tractors only make one pass across a field—during seeding. Weed control is accomplished by sprayers which can use less fuel than tractors pulling tillage implements. That said, large sprayers, some with more than 300 horsepower, can sometimes make 3 or 4 passes over a field in a year. Nonetheless, no-till methods appear to create fuel savings.[35]

Finally, no-till agriculture and its attendant fertilizer and chemical inputs often increase yields. This can positively affect our assessments of GHG emissions. Emissions can be calculated on an output basis (per tonne of grain) or they can be calculated on an area basis (per acre or hectare). When calculated based on output tonnage, if a farming approach increases yield, then per-tonne emissions decrease, *all other things being equal*. To give another example, if a farmer can increase his or her yield by 20%, while emissions rise by only 10 or 15%, per-tonne emissions have decreased. One important caveat, however: Canada and other nations have committed to reductions in *absolute* emissions, not relative or intensity-based reductions. While it is important for policymakers and farmers to think about emissions per tonne of production, we must cut total emissions overall.

No-till agriculture provides some important benefits relative to tillage-based cropping and weed-control systems. No-till systems can increase yields, soil carbon levels, and drought and erosion resistance; and also reduce machinery-related GHG emissions per hectare and per tonne.

… and two steps back

The preceding does not mean, however, that no-till is the best cropping system, or that we cannot design a better one, or that it actually reduces GHG emissions. Indeed, one big problem with no-till agriculture as it is usually practiced is its heavy reliance on fossil-fuel intensive, emission-heavy fertilizers. As no-till agriculture has spread, fertilizer use has increased. In Canada, nitrogen fertilizer use has doubled since no-

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[34] ICF International, "Charting a Path to Carbon Neutral Farming: Mitigation Potential for Crop Based Strategies" (Monsanto Company, June 2016), 1–5.

[35] J. Dyer and R. Desjardins, "Analysis of Trends in CO_2 Emissions from Fossil Fuel Use for Farm Fieldwork Related to Harvesting Annual Crops and Hay, Changing Tillage Practices and Reduced Summerfallow in Canada." *Journal of Sust. Ag.* 25, no. 3 (2005).

till systems began to proliferate in the 1990s (Figure 4-3). It is revealing that Saskatchewan—where no-till agriculture has been adopted most broadly—has had the largest increase in fertilizer use: tonnage has quadrupled since 1991. Figure 7-1 shows the rise in Saskatchewan nitrogen use over the past two generations, and the continued steep upward trend.

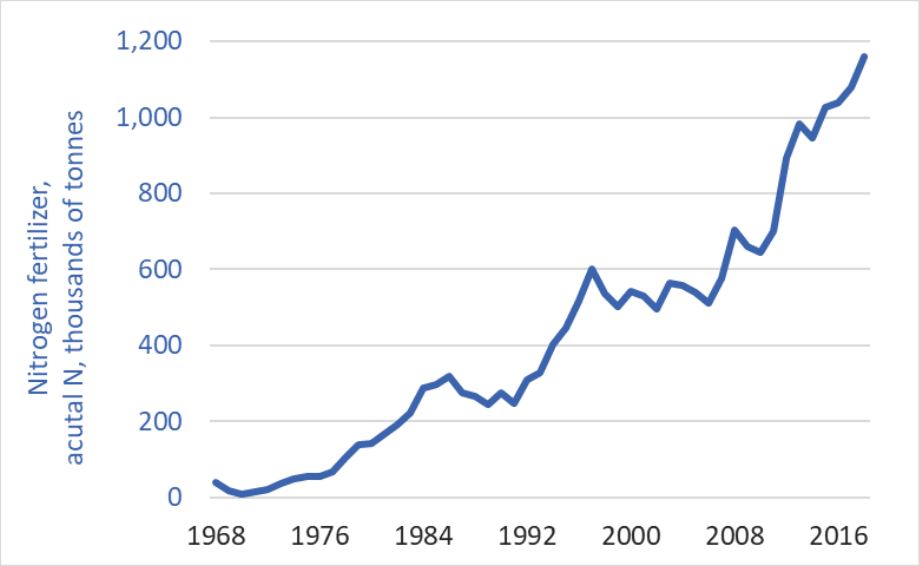

Figure 7-1. Nitrogen fertilizer application tonnage, Saskatchewan, 1968–2018
Sources: Statistics Canada Table 32-10-0037-01 (001-0067); Maurice Korol, Gina Rattray, and Agriculture and Agri-Food Canada (AAFC), *Canadian Fertilizer Consumption, Shipments and Trade 1997/1998* (Ottawa: AAFC, April 1999)

In cropping systems, the largest energy input comes in the form of nitrogen fertilizer. It is therefore not surprising that nitrogen fertilizer is also the largest source of emissions. As we have proliferated no-till cropping systems, energy use and emissions have gone up sharply.

No-till, masking effects, and the risks of being herded down the wrong path

As a proposed solution to the problem of agricultural emissions, no-till cropping systems illustrate the risk of setting out on the wrong path. In the short term, no-till systems can seem to mitigate emissions by moving carbon from the atmosphere into soils. But carbon-sequestration effects are temporary—soil carbon additions (and, thus, atmospheric removals) continue for perhaps just 30 or 40 years. Then soils reach new equilibria and no-till cropping systems cannot further increase carbon levels. As noted by the Canadian government, confirmed by scientists, and illustrated in Figure 5-1, crop-system sequestration rates in Canada are already falling and may be marginal by 2040 or 2050. While the sequestration effects of no-till agriculture will wane within decades, emissions from nitrogen fertilizer seem likely to remain a permanent part of the current no-till approach. If we make the mistake of embracing high-input no-till agriculture, then when the masking effects of soil carbon sequestration dwindle, policymakers may find that they have urged farmers down the wrong path—into a high-input, high-emission cropping system.

It is unlikely that food-production systems that rely heavily on fossil-fuel-intensive fertilizers will be the systems that deliver the emission reductions we need. No-till cropping systems do not appear to be climate or farm-income solutions.

Finally, another potential problem with no-till conventional agriculture is the large and growing volumes of chemical insecticides, herbicides, and fungicides used. Canadian chemical use has doubled or tripled since

1990[36]—about the time no-till agriculture proliferated. These very high rates of chemical use may be having adverse effects on soil organisms and soil ecology. Though no-till methods are promoted as maximizing soil carbon building rates, it may be the case that chemical-induced damage to the biodiversity in living soils is slowing rates of carbon gain. In addition to the many ecosystem effects of elevated chemical use, it would be fruitful to examine the effects of chemical use on rates of soil carbon uptake.

Cropping systems: Nitrogen fertilizer BMPs, 4Rs, & fertilizer caps

So what can we do? Fortunately, research on reducing emissions from nitrogen fertilizer, and reducing its overall use, is well advanced and promising. University scientists, industry partners, and researchers have developed a suite of measures they call "4R nutrient stewardship." The 4 "R"s refer to a set of best management practices (BMPs) that include using the right fertilizer product or source; at the right rate; with the right placement; and with the right timing.[37]

University of Manitoba soil and plant scientist Dr. Mario Tenuta believes that the application of all the 4R techniques in Manitoba could reduce emissions from nitrogen fertilizer by 18 to 30 percent.[38] Fertilizer placement ("the right place") is the "low hanging fruit" of fertilizer-related emissions reduction. Banding all fertilizer below the soil surface rather than spreading some on the surface would allow farmers to cut emissions and reap higher yields due to lower nitrogen losses and more nutrients delivered to crops. Switching from fall to spring application ("the right time") also reduces emissions, as does using certain fertilizer types and coatings ("the right product").

But these findings come with caveats. Even if farmers adopt all 4R measures and other BMPs, emission reductions are not assured. More efficient nitrogen use can also increase yields, improve margins, and lower production costs, and such developments can, in turn, *boost* farmers' fertilizer demand, potentially negating or reversing emissions reductions. As in many cases, efficiency does not lead automatically to reduced use. Moreover, the steep upward trendlines visible in the fertilizer graphs above (Figure 4-3 and Figure 7-1) suggest that efficiency improvements alone will not cause farmers to reduce overall tonnage. Based on this insight, it appears that any strategy to cut emissions from fertilizer by 30 or 50% must also include measures that effectively cap and reduce nitrogen fertilizer tonnage overall.

Fertilizer use can be reduced without adverse effects on yields. For example, once farmers begin using fertilizer more carefully and efficiently, a 15% reduction in nitrogen fertilizer tonnage could cut overall agricultural emissions by 4%, but not necessarily reduce yields or carbon-sequestration rates.[39] Moreover, the 4R techniques (proper placement, optimized rates, coatings, different fertilizer chemistries, etc.) could perhaps further increase that emissions saving, to perhaps 6 or 8%—a good start toward our goal of a 30% reduction by 2030. Moreover, a 15% reduction in fertilizer use could reduce farmers' fertilizer costs, and have beneficial effects on ecosystems, waterways, and the oceans. (For more on nitrogen overuse, please see "Appendix C. Nitrogen-oversaturated Earth.") Farmers must be supported to reduce nitrogen fertilizer use significantly. Our emissions problem dictates that the half-century-long upward trend in nitrogen use, stark in Figures 4-3 and 7-1, must now be inflected downward. Or stated another way, if we do nothing and

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[36] Jules Pretty and Zareen Bharucha, "Integrated pest management for sustainable intensification of agriculture in Asia and Africa." *Insects* 6, no. 1 (2015).

[37] "Tri-Partner Agreement Signed to Enhance Soil Nutrient Management in Manitoba," News release, Province of Manitoba, (January 15, 2013), http://news.gov.mb.ca/news/index.html?archive=&item=16212; T. Roberts, "Right Product, Right Rate, Right Time and Right Place … the Foundation of Best Management Practices for Fertilizer," in Fertilizer Best Management Practices: General Principles, Strategy for Their Adoption and Voluntary Initiatives vs. Regulations: Papers Presented at the IFA International Workshop, 7-9 March 2007 (Paris: International Fertilizer Industry Association, 2007).

[38] Dr Mario Tenuta, "Can Use of 4R Nutrient Stewardship Practices Meet Required Emissions Reductions from Cropped Soils in the Short-Term?" (Phoenix, AR, Presentation to ASA-CSS-SSSA Annual Meeting, November 6, 2016).

[39] Eagle et al., "Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States," 28.

nitrogen fertilizer use continues to increase at current year-over-year rates consumption will be 37% higher a decade from now.

One way to help farmers reduce fertilizer-related emissions would be to impose a small tax on fertilizer, perhaps 2%—less than a dollar per acre, or about $100 million across Canada. That money could be used to fund research on how to reduce/optimize fertilizer use. Funds could also pay hundreds of field staff who could work in the countryside directly with farmers, to assist them in increasing fertilizer-use efficiency, implementing 4R BMPs, finding alternatives to high-cost, purchased fertilizers, and maintaining yields while minimizing purchased nitrogen. Resulting savings could be *several* times the cost of the tax; cutting fertilizer use by 15% could save farmers $850 million per year. By funding fertilizer-efficiency, reduction, and optimization research, farmers can reduce their emissions and increase their net incomes—reduce input use without reducing yields. More generally, farmer-funded research aimed at optimizing input use and reducing use overall is a key strategy to discipline the wealth-extraction power of the dominant agribusiness transnationals.

Improved soil testing can help farmers understand fertilizer needs better. Only a minority of Canadian fields are soil-tested annually or even bi- or triennially.[40] Some experts believe that when testing is done it is often inaccurate, leading farmers to over-apply nitrogen and other fertilizers. Further, soil testing is often conducted by employees of farm-input retailers. Governments and universities should provide independent testing and analysis, incentives for more testing, education for farmers in interpreting test results, more complete and detailed information in those results, information about emissions, and information about alternatives to commercial fertilizers. Provinces should look to other jurisdictions to determine if soil testing protocols and recommended fertilizer rates remain accurate and optimal. Regular, accurate, independent soil testing is an important way to reduce emissions from nitrogen use.

Precision farming technologies can further reduce nitrogen fertilizer use and associated emissions, but these techniques can have unintended consequences for farm incomes and autonomy, which will be examined in detail later in this report.

As we move toward mid-century, to achieve emissions reductions of 50% and beyond, nitrogen fertilizer use will have to be reduced still further and manufactured from low-emission hydroelectricity or other renewable energy sources rather than from natural gas. Another, though less promising, technique is to equip fertilizer plants with carbon capture and storage (CCS) equipment.

Action	**Use a variety of measures—targets, research, incentives, better soil testing, outreach and field staff, etc.—to drive a 15% reduction in nitrogen fertilizer use.**
GHG Savings	Perhaps a 4% reduction in total agricultural emissions.
Costs	Costs to finance research and outreach. But net incomes could rise as revenue reductions were more than offset by cost savings.
Co-benefits	Tackle the larger problem of global nitrogen over-application.
Problems	Challenges in changing practices and adopting new techniques.
Start	2020.
Completed	15% reduction phased in by 2030 (as compared with a 37% increase if current rates of year-over-year increase are maintained between 2020 and 2030).

Action	**Implement fully and aggressively the entire suite of 4R BMPs.**
GHG Savings	Perhaps an additional 2-4% reduction in total agricultural emissions.

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[40] Statistics Canada, *Human Activity and the Environment: Agriculture in Canada: 2014*, Cat. no. 16-201-X (Ottawa: Stats. Can., 2009), http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1407694; Robert Arnason, "Manitoba Leads in Soil Testing, Precision Ag," May 5, 2011, http://www.producer.com/2011/05/manitoba-leads-in-soil-testing-precision-ag/.

Costs	Costs to finance research and outreach. Costs for fertilizer-application equipment or modifications. But net incomes could rise as a result of cost savings.
Co-benefits	Increased crop yields per tonne of fertilizer and, thus, potentially higher net returns.
Problems	Maximizing adoption of BMPs.
Start	2020.
Completed	Fully deployed by 2025.

Action	**Hire and train a large cohort of independent soil specialists to help farmers sample soils, interpret results, understand emissions, and utilize alternatives to fertilizers.**
GHG Savings	None in itself, but supportive of 4R and other measures.
Costs	Costs to finance research and outreach. But net incomes could rise.
Co-benefits	Increased crop yields per tonne of fertilizer
Problems	Capacity issues.
Start	2020.
Completed	Fully deployed by 2025.

Action	**Tax of 2% on fertilizer to fund research on fertilizer use efficiency, etc.**
GHG Savings	Supportive of 4R BMPs, soil testing, and a 15% reduction in tonnage, etc.
Costs	About one dollar per acre, with savings more than offsetting costs.
Co-benefits	Increased crop yields per tonne of fertilizer.
Problems	Collecting taxes and ensuring proper spending.
Start	Immediately.
Completed	Fully deployed by 2025 and ongoing

Action	**Government undertake ambitious programs of data collection, analysis, and publication to quantify the energy use in, energy efficiency of, and emissions from various cropping and food-production systems.**
GHG Savings	Foundational to all other emission-reduction initiatives.
Costs	A few cents per acre, with large savings possible.
Co-benefits	Supportive of farmers' efforts to increase efficiency and reduce costs.
Problems	None.
Start	Immediately.
Completed	Fully deployed by 2023 and ongoing.

The measures above could reduce emissions related to nitrogen use by approximately 30% by 2030, successfully meeting emission-reduction targets for one of the largest components of Canada's agricultural GHG emissions. Further actions can result in additional reductions.

Action	**Work with industry to create nitrogen fertilizer plants powered by hydroelectricity or other low-emission energy sources. Utilize CCS in some cases.**
GHG Savings	Potentially, a large portion of the 11% of agricultural emissions that currently come from fertilizer and chemical production.
Costs	Higher prices for fertilizer.
Co-benefits	None identified.
Problems	Limited supplies of low-emission electricity.
Start	Studies and development in the 2020s.
Completed	First plants operating in the 2030s, providing half of Canadian nitrogen in the 2040s.

Cropping systems: Encourage and support transitions to organic production

Organic producers are demonstrating important ways that *all* farmers can reduce GHG emissions. Organic farmers are producing crops without purchased synthetic nitrogen—finding ways to work with biological processes to get the nitrogen their crops need: using cover crops, legumes, perennials in rotations, and green-manure crops. They are prototyping many of the low-input, low-emission techniques all farmers—including conventional farmers—will need to adopt in coming years.

Studies have found that organic farms usually have higher energy efficiency. (See "Appendix D. Organic agriculture: energy efficiency and emissions" for details on dozens of studies.) This efficiency advantage is largely the result of organic farmers not using natural-gas-derived nitrogen fertilizer. Related studies show that organic producers produce fewer greenhouse gases per hectare, and often per tonne, though this last metric varies from crop to crop and place to place. (See Appendix D.) There are indications that organic sources of nitrogen—legumes, green manure crops, perennials—usually give off lower volumes of GHGs per unit of nitrogen they provide compared to synthetic nitrogen fertilizer. However, more research is needed on this question. And organic production systems build up soil organic carbon levels at rates comparable to conventional no-till systems and thus provide similar benefits in terms of soil structure, carbon sequestration, water infiltration and retention, erosion protection, etc.[41]

Finally, organic farmers usually earn higher net incomes per hectare, partly as a result of premium prices, but also because of lower production costs resulting from reduced input purchases. Higher per-hectare net returns can allow organic farmers to farm fewer hectares and still make a living, and this can enable a region to support more farm families. The precipitous decline in the number of Canadian farms (Figure 1-4) is partly the result of conventional agriculture replacing farmers with petro-inputs and technologies. Organic agriculture, however, does the opposite: replacing petro-inputs with farmers; their management, experience, and wisdom; and a partnership with biological processes.

As we struggle to craft a plan to reduce agricultural emissions, it is illuminating to imagine an organic farm, perhaps a dozen years from now, that uses no purchased fertilizers or chemicals and utilizes low-emission battery-electric tractors. Such a farm would have extremely low GHG emissions per hectare or per tonne. In this mental picture we catch a glimpse of the farms that could deliver the 50% emission reductions needed by 2050, and perhaps even move us close to net zero.

But as promising as it is, the acreage and number of organic farms cannot be increased sufficiently or rapidly enough to make it the primary model of crop production or mixed-farm agriculture in Canada. Organic farms now occupy just 1% of Canada's cropland.[42] The number of organic farms, and their farmland area, should probably be increased five- or tenfold—to encompass at least 10% of Canada's cropland in the coming decades, but there are limits on organic acreage. For example, it might not be possible to multiply organic production twenty- or thirtyfold and still retain price premiums. Rapidly rising supplies would overwhelm demand and erase premiums. Governments should not encourage farmers into organic production beyond the levels at which we can be reasonably sure that premiums will be mostly unaffected. That said, governments do need to provide much more support to organic producers, and to remove roadblocks for those eager to make the transition.

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[41] A. Gattinger et al., "Enhanced Top Soil Carbon Stocks Under Organic Farming." *Proceedings of the National Academy of Sciences* 109, no. 44 (2012).

[42] 876,096 cropland acres out of Canada's total of 87,352,431 cropland acres. Canada Organic Trade Association, "Organic Agriculture in Canada: By the Numbers," March 2017, https://www.organiccouncil.ca/wordpress/wp-content/uploads/2017/03/Org_Ag_Canada_overview_17.02.27-FINAL.pdf .

Another limitation of organic agriculture can be lower yields. Studies show that organic yields are often 8 to 25% below those for conventional farms—more for some crops and less for others.[43] This century, humanity may increase its population by nearly 50%—raising our numbers to perhaps 11 billion. In light of this, moving too aggressively toward an agricultural system that may reduce supplies will cause concerns. Organic farms can "feed the world." But there are many considerations before us that go far beyond that tired, simplistic debate.

The third and fourth limitations of organic agriculture are related: weed control and tillage. Weed pressures often reduce yields. Related to this factor, most organic farmers must till more to control weeds and to break up perennial crops or cover crops. Many farmers are convinced of the merits of reduced tillage and are thus wary of moving into crop-production systems that require significant tillage. As we struggle to find ways to produce our food with fewer emissions, the reduced tillage aspect of no-till conventional agriculture is a benefit that should be retained wherever possible.

Finally, organic agriculture entails increased paperwork to maintain certification and ensure traceability. Not all farmers welcome the additional paperwork requirements.

Despite these limitations and challenges, and because of organic agriculture's many strengths and benefits, the number and area of organic farms should be multiplied.

Action	**Implement policies and incentives that cause farmers to multiply Canada's organic area at least threefold by 2030 (to at least 3% of cropland) and at least tenfold by 2050 (to a minimum of 10%). Embark on market-support programs that enlarge markets and maintain premiums.**
GHG Savings	Uncertain. Canada-specific studies must be undertaken, but it is likely that per-hectare emission reductions will be in the 20 to 40% range. Further, organic farms using electric tractors begin to get us to the net zero emission levels needed by mid-century.
Costs	Reduced incomes during transition years.
Co-benefits	Increased prices, reduced input costs, higher net incomes.
Problems	Weed control, tillage, paperwork, reduced yields
Start	Immediately.
Completed	2030: at least 3% of cropland area; 2050: at least 10% of cropland area.

it is not clear what form our future climate will take. Faced with such uncertainty, the responsible course is diversification: make our food-production base as diverse and adaptable as possible. But if most of our cropland is farmed in one way (perhaps by large, highly-indebted, high-input, low-margin, no-till conventional farms employing costly specialized equipment) that system will lack the diversity, adaptability, resilience, and capacity for the rapid change necessary to adapt to a destabilized, dynamic climate. By multiplying organic acreage, we diversify our production systems and, because organic farms tend to be smaller and more intensively managed, we multiply the number of skilled, experienced farmers on the land. Organic farming brings benefits in itself, but it confers the meta-benefit of adding diversity and human capacity to our agricultural landscape. ***Adding thousands of organic farmers to the Canadian countryside means adding thousands of knowledgeable women and men who are used to thinking carefully about the interface between farming and biology, expert in solving agronomic problems without purchased inputs, and open to experimenting with new techniques.*** There is no better way to position Canadian agriculture to work through the coming climate and crop-production challenges than to multiply the number of organic farms, farmers, and acres.

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[43] J. Reganold and J. Wachter, "Organic Agriculture in the Twenty-First Century," *Nature Plants* 2 (2016).

Cropping systems: A different paradigm: Minimum-Input No-Till (MINT)

Organic crop-production systems have many benefits, but also limitations. This is true for no-till systems as well. Neither system offers an ideal model as we strive to achieve large emission reductions while improving farm incomes. But a range of *hybrid* approaches hold promise—approaches that, in different proportions, combine the strengths of no-till conventional with those of organic and other systems. The most climate-friendly agricultural system over the long term is probably one that blends:

1. the most promising organic techniques (incl. sophisticated crop rotations, legumes, perennials, cover crops, intercropping, etc.) to minimize purchased inputs, especially nitrogen fertilizer; with
2. no-till techniques (including strategic use of herbicides, low-disturbance seeding tools, etc.) that reduce tillage and fuel use and increase ground cover, erosion resistance, and yield.

We will call this pragmatic hybrid production system Minimum-Input No-Till (MINT) agriculture. Consider this question: What production method would enable a farmer to produce a tonne of corn or wheat with the lowest emissions? The answer probably is not "organic agriculture." A more likely answer is that the lowest emissions would come from hybrid systems—those that minimize the use of petro-inputs, use strategic but limited quantities of pesticides to control problem weeds, use only moderate amounts of fertilizers to overcome nutrient constraints, and use soil-building no-till methods. Organic acreage cannot be expanded to encompass most of Canada's cropland, so we must find ways to slash emissions from non-organic acres. ***MINT agriculture transplants the best cost- and emission-reducing practices from organic agriculture into conventional and retains the benefits of no-till cropping systems.***

Humanity faces *multiple* problems: the climate crisis; low farm incomes; the challenge of feeding billions more people without expanding farmland area; nutrient loading in waterways; topsoil loss; and the fastest extinction event in 65 million years, to name a few. In the near term—until we can implement more sweeping civilizational transformations—the best solution to all these problems is to take the best aspects of organic agriculture (high energy efficiency, low input use, low emissions, lower costs, higher margins, diversified approaches to weed control, etc.) and the best aspects of no-till (less tillage, less fuel use, higher yields, the potential for land-saving, etc.) and fuse these into a new paradigm. Such an approach could be part of a larger, food-system-wide approach that minimizes emissions per unit of nutrition—that minimizes food waste, transport distances, over-processing, and the denutritionalization of foods.

While some may see this organic-min-till hybrid as ambitious or radical, it is not: it is incremental and pragmatic. It is also inevitable. As farmers take steps to reduce emissions by one-third and then one-half and as Canada moves toward carbon neutrality, fertilizer use will have to be cut to a fraction of current tonnage. As this happens, *all* farmers will become much more interested in nitrogen-fixing crops, diversified rotations, and maximizing fertility and yield while minimizing high-emission inputs. ***In the future, even the most ardent practitioners of high-input no-till agriculture will have to make changes on their farms and adopt approaches that resemble those currently in use on organic farms.*** There will also be a need to expand the acreage of other production systems, ones that can be partially described with labels such as agroecology, permaculture, Holistic Management, and other approaches that seek to re-integrate human food production with the cycles, flows, and processes of biology and ecology.

There is a lot of evidence that low-input agriculture can deliver cost, energy efficiency, and emission benefits when compared to conventional no-till systems; and that low-input agriculture can deliver yield benefits when compared to organic.[44] To give one example, a 2007 study detailing the results of a nine-year field trial

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[44] F. Alluvione et al., "EUE (Energy Use Efficiency) of Cropping Systems for a Sustainable Agriculture." *Energy* 36, no. 7 (2011).

in Maryland sums up the strengths and weaknesses of organic agriculture and suggests a hybrid alternative.[45] The authors state that by the end of their study, in the organic system "competition with corn by weeds … was unacceptable, particularly in dry years." On average, corn yields were 28% lower in the organic system than in the no-till system. But the organic system displayed many strengths, including superior soil-building and nutrient availability. And despite tillage, carbon levels and nitrogen in the organic plots were higher than in plots cropped with other systems. At the end of the experiment researchers tested the idea that organic systems made available more nutrients. They planted corn on all plots. No fertilizer was added. All plots were managed in the same way. The plots that were previously farmed using organic methods yielded 18% higher than those that received the no-till treatment, indicating superior inherent fertility, increased nutrient availability, and healthier soil biology. The researchers concluded: "These results suggest that [organic agriculture] can provide greater long-term soil benefits than conventional [no-till], despite the use of tillage in [organic systems]. However, *these benefits may not be realized because of difficulty controlling weeds*" [italics added]. This study and many others suggest that a complete solution lies in fusing the best aspects of organic and no-till cropping systems—adding a limited amount of chemical weed control to organic systems. A hybrid low-input system can best balance our needs to cut emissions, maintain yields, limit agricultural land area, protect the environment, increase farm incomes, and expand the number of family farms.

It may even be the case that MINT agriculture can protect biodiversity and sequester carbon faster than organic systems. Key is the concept of "land sparing." MINT agriculture and its strategic use of chemicals and fertilizers will have higher yields than organic systems. Another way of thinking about higher yields (higher output per area of land) is the converse: producing the same quantity of output on a smaller area. For example, imagine we want to produce 25,000 bushels of wheat. On the Prairies, an organic system might require 1,000 acres (assuming 25 bushels per acre). But a MINT system might require just 800 acres (yield 30+ bushels per acre). To produce the same amount of grain, the MINT system can free up 200 acres—land that can be put into set-aside programs, planted to grasslands or forest, and used as wildlife habitat. If that happens, the biodiversity effects and other benefits from the MINT system's 800 acres of cropland plus 200 acres of set-aside could be comparable to the organic system's 1,000 acres of wheat. MINT may challenge organic agriculture as the most environmentally friendly—though this last point will stir controversy, and such controversy is healthy and productive as we struggle to expand our thinking to tackle the daunting emissions and climate problems we face.

Taking the best ideas from organic and no-till approaches and creating a hybrid MINT system can reduce inputs, increase energy efficiency, reduce emissions, maintain yields, protect water and soil and biodiversity, reduce farmers' costs, increase net returns, help increase the number of farmers on the land, and give us another option for organizing and diversifying agriculture into the future.

Action	**Use government resources, thousands of civil-servant agrologists, information programs, and tax incentives to proliferate a MINT crop-production system on 30% of Canada's cropland acres by 2030 and 50% by 2050.**
GHG Savings	Dependent on input-use levels, but emissions likely 10 to 20% less than high-input no-till. This reduction would come on top of others, including 4R practices, etc.
Costs	Altering production practices creates costs. Reduced input expenses can offset these.
Co-benefits	Lower input costs and potentially higher net incomes.
Problems	Agronomic challenges in the transition phase.
Start	2020.
Completed	30% of cropland by 2030, and ongoing.

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[45] J. Teasdale, C. Coffman, and R. Mangum, "Potential Long-Term Benefits of No-Tillage and Organic Cropping Systems for Grain Production and Soil Improvement," *Agronomy Journal* 99, no. 5 (2007): 1297.

Cropping systems: Rotations and crop selection

Adding perennial forages to rotations of annual crops can help supply nitrogen, sequester carbon, build soils, and decrease fuel use and emissions. Lower-emission crop-production systems of the future will likely include an increased use of perennial crops in rotations, and more complex rotations overall.

A comprehensive report that reviews data from several US studies concluded that including one to three years of perennials (including alfalfa or grass hay) in annual crop rotations can reduce nitrogen fertilizer requirements, CO_2 from field operations, and N_2O emissions from fertilizer use.[46] Without going into detailed calculations, emissions savings could be in the range of 1 to 3% of total agricultural emissions. This same review also noted that including perennials in rotations may increase the rate for soil carbon sequestration. Again, though, it is important to distinguish between carbon sequestration and emission-reduction effects.

The downside is that lower revenues may result from growing perennial rather than annual crops. Offsetting this, to some extent, could be lower production costs during years when perennials are growing, but also lower production costs during years when annual crops are growing because lower nitrogen requirements and higher soil carbon levels can reduce costs and increase yields. More study is needed on the agronomic, emission-reduction, and farm-profitability effects of adding perennials to rotations.

Finally, although these are promising measures, we need to keep in mind that agriculture is a complex and interconnected *system*. If we increase the area of perennial crops—adding an area equivalent to another 10 or 20% of Canada's cropland—and if a portion of that perennial crop production is harvested as forage, the question then becomes: what will eat all that livestock feed? Will the cattle herd increase in size? If so, by how much might enteric methane emissions increase? Individual changes cannot be examined in isolation. A whole-system approach is necessary. Promoting perennials in rotations of annuals must be examined in the largest possible context.

Similarly, cover crops and intercropping appear to be very positive and could hold the keys to significant reductions in GHG emissions. The NFU strongly urges all governments and academic institutions to comprehensively examine these approaches and to work with farmers to bring them into the mainstream of cropland stewardship.

Action	**Federal and provincial governments should work with universities to initiate and fund additional studies of the potential for GHG emission reductions from the increased use of perennial crops in rotations of annual crops, intercropping, and cover crops.**

Cropping systems: Precision farming and agricultural Big Data

An analysis of precision farming technologies reveals why it is critical to evaluate emission-reduction technologies in their political, economic, and social contexts. Precision farming technologies can provide significant emissions reductions; they could, however, also have negative effects on farmers' autonomy, incomes, market power, and even on the capacity of smaller operations to remain in business.

Precision farming is a set of technologies and approaches that collect and integrate information about crop yields, soil fertility, topography, water, weather, and location and use that information to:

- help make decisions about input use;

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[46] Eagle et al., "Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States," 15.

- continuously vary application rates on seeders or sprayers as they move across a field; or
- control machinery in other ways that increase efficiency, decrease input use, or increase yields.

Examples of precision farming techniques include:

- utilizing data from soil tests and the previous years' yields to create fertilizer-application maps and using those maps to continuously vary fertilizer rates during seeding;
- spot spraying based on GPS data collected during field scouting; and
- turning off spray booms or seeder sections to avoid overlap and double application.

Precision farming hardware and software can increase yields and input-use efficiency, and decrease input use, costs, and GHG emissions. Experts' reports and science journal articles claim that precision farming techniques can reduce crop-production emissions by several percent.

The problem is that precision farming tools often come attached to another suite of technologies: agricultural Big Data. We can grasp the difference between the two sets of technologies this way: In precision farming, a farmer could collect data and use that information to control his or her farm machinery to increase input-use efficiency or yields and the data could stay on his or her farm, wholly under his or her control. In contrast, Big Data brings other powerful players into the mix. In such systems, a farmer's data would often be collected by a networked "technology platform" with data links, not only to the technology provider or machinery company that made the hardware or software, but often to the dominant seed, chemical, and fertilizer corporations. In agricultural Big Data systems, the farmers' data is often housed, not on his or her farm, but in the cloud, on servers controlled by input or machinery companies. There is significant potential for farmers' data to be used in ways that hurt farmers. For example, the data could be used to police farmers' use of patented seeds, identify high-yielding land for speculative buy-up, even to gain an advantage in futures markets. For details on precision farming and Big Data see Appendix F.

Here is another factor: Precision farming technologies are not scale neutral. These systems—costly both in terms of money and managerial time—are best suited to large farms that can afford newer equipment, spread costs over thousands of acres, and assign an employee or family member the task of managing the information systems and hardware.

Finally, there is a probability that precision farming technologies, touted as profit-enhancing options, will be turned into costly necessities as every farmer is forced to purchase the hardware and services in order to remain competitive, or to comply with emission-reduction dictates.

Precision farming and Big Data platforms—as currently deployed, tied to the dominant agribusiness corporations and raising a clear risk that farmers' data could be used against them—should not be part of a climate change solution for farmers. Appendix F provides more analysis, and suggested remedies.

Cropping systems: Orderly marketing, disorderly transport, and emissions

For Prairie grain farmers, the past four decades have been a time of deregulation, privatization, and the destruction of farmers' co-ops and marketing agencies. Western farmers have witnessed the loss of the Crow Rate and Crow Benefit; the privatization of Canadian National Railway; the loss of their farmer-owned grain-handling co-ops; widespread destruction of branch lines and elevators; the weakening of the Canadian Grain Commission (CGC); and the loss of the Canadian Wheat Board (CWB). Though much of this loss, destruction, deregulation, wealth transfer, and corporate empowerment proceeded under the rhetoric of "rationalization," the results have been anything but rational. Although quantitative evidence and data are largely absent, it is very likely that the past 35 years have been a time of rising GHG emissions from the grain handling and transportation system (GHTS). Grain appears to be moving longer distances, often on trucks instead of trains, and in a less coordinated, less efficient way.

The most material manifestation of the deregulation of our GHTS is the destruction of railway branch lines and grain-delivery points. This has increased trucking distances. Compared to trucks, trains use a fraction of the energy per tonne-kilometre and produce a fraction of the emissions. By forcing grain to travel further by road, grain companies and railways have pushed emissions up.

Further, it is almost certain that the loss of the CWB and its central logistics role in the GHTS has also pushed up emissions. The CWB was able to consider the whole of western Canadian wheat and barley production and stocks, consider all sales for those grains, look out over the long term, evaluate the capacities and constraints of railways and ports, and move grain in ways that were efficient and cost-effective. The fragmented, disorganized system now in place almost certainly moves grain less efficiently, and with higher emissions and costs, than was the case under a CWB-coordinated system.

Once things are destroyed, it is hard to get them back. But as we struggle to reduce emissions, as we are forced to make costly investments to do so, and as we are forced to make difficult choices, it is clear that it would be beneficial to have a rural Canada criss-crossed with railway lines, a grain-delivery system that minimizes high-emission truck transport, and centralized transportation coordination (such as the CWB) to draw grain into the system and deliver it to locations in ways that minimize costs to farmers and emissions to the atmosphere.

Action	**Reinstate single-desk selling of wheat and barley and restore the CWB to its critical role in grain handling and transportation logistics and coordination; rebuild Canada's rail and elevator networks and work to minimize truck-transport distances and emissions.**
GHG Savings	Not yet calculated.
Costs	Initial costs of building infrastructure may be high, but farmers will benefit from lower transportation costs and, thus, higher farm-gate grain prices.
Co-benefits	A rebuilt rail system could also be used for efficient transportation of other goods.
Problems	
Start	2020.
Completed	2030

Chapter 8: Climate-Compatible Livestock

If regenerative agriculture exists, it is likely found in mixed-farming systems that utilize natural nutrient cycles; diverse animal and plant mixes; sensitive management; and best-possible grazing methods to restore soils, raise carbon levels, protect water, enhance biodiversity, and support sustainable livelihoods.

Increasingly cattle are being blamed for a number of environmental ills. It is true that cattle and their production systems are sources of greenhouse gases (see Figure 4-1). On the other hand, cattle and other grazing animals are indispensable parts of healthy grassland ecosystems and sustainable mixed-farming operations. This section lays out the case against cattle and the case to be made *for* cattle. In the end, as in most such situations, reality is far more complex than the often simplistic or under-informed arguments on offer. This section deals mainly with beef cattle production systems, though many points are equally applicable to dairy cattle, and some to other livestock types.

Livestock systems: The case against cattle

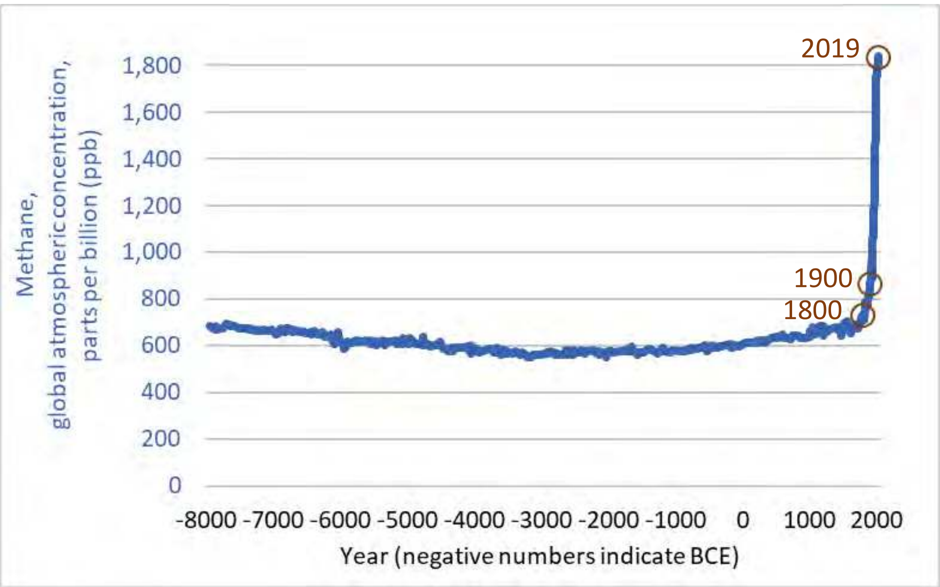

Figure 8-1. Global atmospheric methane concentrations, past 10,000 years
Source: US EPA, "Climate Change Indicators: Atmospheric Concentrations of Greenhouse Gases," www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases

Humanity has a methane problem. Figure 8-1 shows global atmospheric methane (CH_4) concentrations for the past 10,000 years (8,000 BCE to present). Methane is one of the three main GHGs, and 28 times more effective than CO_2 at trapping heat. Humans have tripled methane concentrations. This increase has four main causes: coal, oil, and gas production (natural gas is mostly methane); organic decomposition in landfills; rice paddy agriculture; and livestock production—methane emitted from the mouths of cows and other ruminants as they digest grass, and from manure. Figure 8-2 gives a sense of the relative sizes of the methane flows from human sources. Unfortunately, this long-term dataset ends at 1994. Nonetheless, it gives an indication of the relative sizes of emission sources and their evolution over much of the past century-and-a-half.

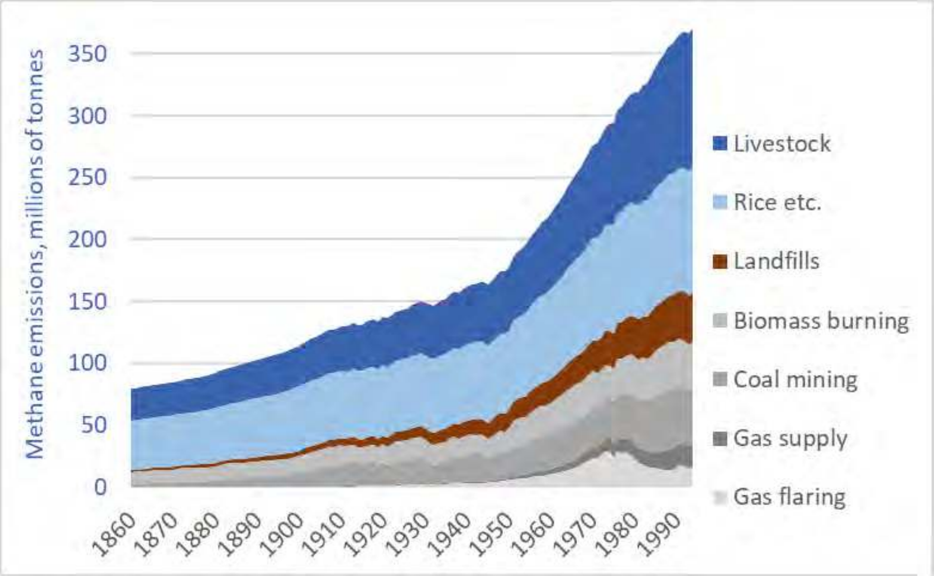

Figure 8-2. Emissions of anthropogenic methane, 1860–1994
Source: D. Stern and R. Kaufmann, Boston University Center for Energy and Environmental Studies, https://cdiac.ess-dive.lbl.gov/ftp/trends/ch4_emis/ch4.dat

This report will nuance the picture painted by these two graphs, show how cattle production may be made compatible with stable atmospheric methane concentrations and a stable climate, and show that herbivores on grasslands are critically important parts of many ecosystems.

But first, one thing must be acknowledged: the numbers of livestock animals are now *huge*. The mass (tonnage) of domesticated animals is now approximately 20 times that of the mass of wild animals (land mammals and birds).[47] Stated another way, if we add up the weights of all the cows, sheep, pigs, horses, chickens, llamas, cats, hamsters, etc., that total is 20 times the weight of all the wild terrestrial mammals and birds: all the elephants, mice, pandas, cheetahs, bats, bears, deer, wolves, chickadees, herons, eagles, etc. The mass of chickens is more than double the total mass of all other birds on Earth, combined. There are too many livestock animals on the planet, and humans and our livestock have taken too much land area for ourselves and left too little for wild animals and non-human ecosystems. This is a primary cause of the mass extinction now unfolding—the most rapid extinction in 65 million years. While we must find ways to safeguard livestock producers, livestock production, farm incomes, mixed farms, and the important ecosystem benefits grazing animals bring, the number of animals must be cut. Appendix G provides data on human, livestock, and wild-animal biomass over the past 50,000 years. Please look at Appendix G.

Understanding methane from cattle

Humans cannot digest grass. Cellulose, which makes up most grass biomass, is especially difficult to digest. Cattle and other ruminants can digest grass, because their multiple stomachs host symbiotic bacteria that break it down into simpler compounds. But those bacteria live in an airless "anaerobic" environment. Without air there is little oxygen, so these bacteria breath out methane (CH_4) rather than carbon dioxide (CO_2). As cattle digest grass and forage their stomach bacteria emit the greenhouse gas methane, which cattle expel, mostly out of their mouths. The methane problem is not created by feedlots, grain feeding, or "factory farming." These practices create environmental problems (including huge upstream emissions from fertilizer use and feed production), but they are not the reason we have a methane problem.

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[47] Y. Bar-On, R. Phillips, and R. Milo, "The Biomass Distribution on Earth," *Proceedings of the National Academy of Sciences* 115 (2018); A. Barnosky, "Megafauna Biomass Tradeoff as a Driver of Quaternary and Future Extinctions," *Proceedings of the National Academy of Sciences* 105 (2008); V. Smil, *Harvesting the Biosphere: What We Have Taken from Nature* (Cambridge: MIT Press, 2013)

What about bison?

Bison are also methane-emitting ruminants. And there were tens-of-millions of bison in North America before settlers arrived. How can cattle be an emissions problem if millions of bison grazing for thousands of years were not a problem? The answer has two parts: First, there are now more cattle than there were bison, and those cattle emit more methane. Second, today the methane from cattle comes alongside huge plumes of methane from other activities: energy production, landfills, and rice paddies (see Figure 8-2).

Estimates of the size of North America's historic bison herd vary. Recent studies based on first-person accounts, historical records, and carrying capacity estimate a bison population of 30 to 60 million animals, with many estimates falling near the bottom of that range. Today, Canada, the US, and Mexico host about 130 million cattle and calves. North America's ruminant methane emissions may be far higher than those of the bison. On top of this, the more than 700 million cattle in Eurasia almost certainly dwarf, in numbers and emissions, the populations of wild ruminants that may have existed on those continents in recent millennia. A recent science journal article estimates that global ruminant methane emissions today are more than twice as high as in 1800. And today, 92% of global ruminant emissions come from domesticated livestock.

Livestock systems: The case *for* cattle

The previous section lays out the case against cattle. But that is barely the beginning. There is also a strong case *for* cattle. Cattle are essential components of healthy grassland ecosystems that build soil and capture carbon; they enable us to produce food on land that could otherwise not produce food or that should not be cropped; and they are part of sustainable, nutrient-cycling mixed farming operations. Atmospheric methane levels can be stabilized and even reduced even as cattle production continues (though restructuring will be needed). Moreover, a move away from corporate-controlled output-maximizing cattle production systems can increase the net incomes of cattle producers and increase the number of family farmers raising cattle.

All sustainable ecosystems include animals

All natural ecosystems include animals and all grassland ecosystems have included herbivores, usually ruminant herbivores. Before European contact, North America's plains were home to tens-of-millions of bison. Similarly, African and Eurasian grasslands existed in a symbiotic relationship with huge herds of grazing animals. Herds of wild cattle—aurochs, the ancestors of modern cattle—have roamed Earth's grasslands for millions of years. Grasslands co-evolved with grazing animals, and grassland health and productivity decline if grazers are absent. It has been said that "God doesn't farm without animals."

Imagine the blight of human-created agricultural landscapes that banish animals—that include only chem-forced monocultures of corn, canola, wheat, soybeans, or potatoes. Such rural landscapes would be empty, lonely, wholly unnatural and unsustainable, massively dependent on petro-industrial inputs, and emitters of vast quantities of GHGs. As we look at methane dynamics in the biosphere, we see that grassland ruminants are not inherently a problem. Through several errors and bad choices, however, humans have turned those animals into a problem. These are errors we must now reverse.

The alternatives to cattle may produce higher emissions

This report has at its core the idea that farming is a system, and our farming system is embedded in a set of larger systems we call ecosystems and the biosphere. Because these are systems, if we change one thing it affects all other things. When dealing with systems, you cannot make just one change. Therefore, we need to ask, what will happen if farmers dramatically reduce cattle numbers, as some advocate? The pastures and hayland that formerly fed many of those cattle and supported farm families would likely be put to other uses. Large areas might be turned into cropland. However, when a farmer breaks up grassland or hayland that land begins to lose carbon—emitting it as CO_2. Then, when the farmer plants a crop on that former pasture or hayland he or she will probably fertilize those fields, and that fertilizer will emit nitrous oxide, a powerful greenhouse gas. Simplistic steps to remove grassland herbivores from our farm and food systems could fail to reduce emissions, and could even increase them.

Good cattle management builds soil

The arguments for cattle go far beyond the idea that the alternatives could be worse. Good cattle management brings many benefits to the land and to the ecosystems in which they are raised. Grazing—especially enhanced methods such as rotational grazing—can take carbon dioxide right out of the air and bind it into the earth as “soil organic carbon.” Increasing soil carbon levels and organic matter in this way can build topsoil, enhance fertility, and help retain water. The Earth’s grazing lands could sequester billions of tonnes of carbon in coming decades. Indeed, some people make the argument that cattle can actually sequester more GHGs than they produce—that their soil carbon sequestration effects can exceed their enteric methane emissions. They point to studies that show that cattle in best-possible grazing systems can reduce, not increase, atmospheric GHG concentrations.

Comparing the pluses and minuses and looking for direction

So, which is it? Do cattle and beef production drive warming and climate change? Or can improved grazing be an emissions and climate solution? There are no clear answers to those question. The questions are oversimplifications that have no real relevance when applied to diverse grassland ecosystems. “Appendix H. The emissions balance of cattle,” provides detailed estimates of emissions per animal and per pound of beef, and it summarizes results from numerous studies regarding the probable scale and rate of soil carbon sequestration. In the end, there is no real answer to the question of the relative balance between cattle emissions and soil sequestration. Based on an initial survey of the data, *and being open to revising our understanding as time goes on*, this report takes the following positions:

1. It is almost certain, given the range in the published data, that grazing practices can be devised that will lead to soil carbon sequestration rates that exceed enteric methane emissions. Some cattle production systems can be net negative—removing more GHGs than they produce.
2. While enteric methane emissions are relatively predictable and constant (influenced mostly by feed quality) soil carbon sequestration rates can vary widely as a result of rainfall rates, initial soil condition, growing-season length, etc.
3. Though grazing best management practices (BMPs) can, in some places and at some times, lead to soil carbon sequestration rates that exceed cattle methane emissions, evidence is lacking as to how broadly such results could be replicated, how long such conditions may last, or how consistently this might occur.
4. Eventually, soils approach new carbon equilibria, and sequestration rates slow, stop, or reverse. Stated another way, sequestration happens fastest on the most degraded land and slowest in the carbon-richest soils. So, initial success at sequestering carbon will eventually slow our success at sequestering carbon. For more on this see “Appendix B. Soil carbon sequestration.”
5. Because BMPs such as rotational grazing are not the dominant mode of cattle management in Canada, it is almost certain that methane emissions from cattle today far outweigh soil carbon-sequestration effects. Moreover, it is unlikely that most of the Canadian herd will be managed in a way that would make those cattle GHG-neutral or -negative.
6. Increasing soil carbon levels is an absolute good—enhancing water-holding capacity, soil health, grass productivity, etc.—*and should be pursued regardless of emissions-balance calculations*.

7. Soil carbon sequestration and emissions should be accounted for separately. The one should never be netted out against the other.
8. For decisions around livestock production, it is not the proper standard to require a given production or grazing system to be GHG-neutral or -negative. For millions of years, ruminants grazing on grass emitted methane and other processes in the biosphere and atmosphere consumed or otherwise destroyed that methane. The fact that cattle emit methane does not disqualify the idea that we should continue to farm using grazing animals on healthy grassland ecosystems. Cattle herds and cattle farms can be part of an Earth system that balances methane production and destruction and that has stable GHG levels and a stable climate.

Cattle create a big problem in terms of a certain greenhouse gas: methane. However, as we pursue systemic, holistic transformation of our farms and food systems we must not fixate on just one variable—one gas. We are pursuing *multiple* goals: reducing emissions; stabilizing the climate; protecting our soils and water; preserving biodiversity; supporting Canadian farm families and their incomes; and supporting diversified and buoyant provincial and national economies. Cattle production systems can be, and must be, restructured to contribute to all these goals.

One final point in this section: *sustainability* is not the gold standard. Working to attain sustainability, though difficult, is not very ambitious. Sustainability is just the mid-point between damaging and regenerative. One can "sustain" a system in a degraded state—keep it from becoming worse. But other practices, better practices, can improve or regenerate that system. ***If regenerative agriculture exists, it is likely found in mixed-farming systems that utilize natural nutrient cycles; diverse animal and plant mixes; sensitive management; and best-possible grazing methods to restore soils, raise carbon levels, protect water, enhance biodiversity, and support sustainable livelihoods.*** That said, price-minimizing, production-maximizing commodity systems controlled by huge transnational meat companies are almost never sustainable, let alone regenerative: they are damaging, dissipative, and climate-incompatible. Cattle and other ruminants are not the problem. Human corporate-economic systems and the way they have misshaped and degraded livestock production are the problem. Cattle can be compatible with a stable climate, but the current cattle-industrial complex cannot be.[48]

Cattle are only one part of the problem when it comes to methane

This chapter opened with graphs showing the past 10,000 years of atmospheric methane concentrations and the main human sources of methane. A few observations can begin to frame the problem and point the way to solutions. Humans domesticated cattle about 10,000 years ago. For the first 9,900 years of cattle farming, methane concentrations in the atmosphere did not go up (Figure 8-1). Methane concentrations were stable partly because the atmosphere contains processes (and, to a lesser extent, the biosphere contains organisms) that break down methane. For millions of years, ruminants have ranged over much of the Earth and these animals did not trigger a runaway warming event because cattle emissions and the methane emissions from other herbivores and from wetlands and many other natural sources were in balance with the methane sinks. Organisms that emitted methane (including wild and domesticated ruminants) were in balance with processes and organisms that removed methane.

However, in the 20th and 21st centuries human-caused emissions of methane overwhelmed the processes of the atmosphere and biosphere that would otherwise balance methane concentrations. As a result, we have seen atmospheric concentrations triple in the past 100 years. Figure 8-2 shows the rapidly rising emissions from the fossil fuel sector, from landfills, and from other sources, including cattle.

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[48] For information on emissions from the dominant livestock-product processing corporations, see GRAIN and IATP, *Emissions Impossible: How Big Meat and Dairy Are Heating Up the Planet* (IATP & GRAIN, 2018).

The larger context

We must draw back and assess cattle in a wider context—as parts of planetary systems of life and land. First, let us acknowledge how profoundly strange it is that we humans are debating whether we will allow animals to roam the open spaces of the Earth. All sustainable natural ecosystems include animals—diverse, interconnected webs of animals and plants. When we close our eyes and imagine sustainable natural ecosystems, we picture landscapes teeming with animals. Our climate crisis is the result of one type of error. Deciding to create agricultural landscapes devoid of animals would be another type of error.

Agriculture and Agri-Food Canada (AAFC) scientist Henry Janzen does a good job of placing livestock in an ecological and cultural context in his 2011 article "What Place for Livestock on a Re-greening Earth?"[49] He captures the essence of humanity's dilemma as we strain to feed 9, 10, or 11 billion people on a warming, depleting, deteriorating Earth. Janzen frames the question in broad terms: "Do livestock hinder or advance our aims to sustain the land in perpetuity?" To Janzen, "land" means soil, but also humans, our communities, the climate, and all living things—the species and ecosystems that must be protected and sustained into the future. Janzen challenges us to see livestock, agriculture, and the stewardship of the Earth in their proper means-ends relationship. He reminds us that our ultimate goal, our ultimate end, is to sustain the land (the soil and all species) in perpetuity. Agriculture, cattle, farms, markets, technologies, and specific food-production practices can be *means* to that end. Or they can be means to the opposite end: the destruction of the land: the soil and all species. In making decisions about how we reduce emissions of certain greenhouse gases—whether from cattle or tractors or fertilizers—we must keep our ultimate end in mind: to sustain the land in perpetuity.

With regard to cattle and other livestock, Janzen and others point out a number of food-system, ecological, and cultural benefits of well-managed livestock systems, including:

1. Expanding the human food supply by turning inedible plants (grasses) and un-cultivatable lands (hillsides, rangelands, etc.) into food for humans;
2. In traditional cultures, storing food supply surpluses from one year to the next and acting as a form of portable wealth;
3. Producing food with much lower (or even zero) fossil fuel requirements;
4. Supporting the cultivation of perennial forage crops, which are (or can be) important parts of low-input, soil-building crop rotations;[50]
5. Recycling plant nutrients and decreasing the need for nitrogen fertilizer;
6. Enabling farmers to earn income from land that cannot, or should not, be cultivated (much of Canada's farmland is not suited for tillage or crop production);
7. Increasing water infiltration (forage crops and grasses are relatively deep rooted) and tapping into deeper soil moisture;
8. Protecting soil from erosion; and
9. Providing wildlife habitat, increasing biodiversity, and providing "restorative disturbance" and serving as "instruments of conservation and renewal."[51] Many of Earth's plants and ecosystems evolved in a symbiotic relationship with grazing animals. As Canadian scientists Lynch et al. remind

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[49] H. Janzen, "What Place for Livestock on a Re-Greening Earth?," *Animal Feed Science and Technology* 166 (June 2011).

[50] S. Kulshreshtha et al., "Economic and Greenhouse Gas Emissions Impacts of Doubling of Forage Area in Manitoba, Canada." *Canadian Journal of Soil Science* (2016), 2.

[51] H. Janzen and C. Campbell. "Management Effects on Soil C Storage on the Canadian Prairies." *Soil and Tillage Research* 47, no. 3–4 (1998), 787.

> us, "Net primary productivity is lower in the absence of grazing. Native rangeland plants have co-evolved with rangeland animals…."[52]

Cattle create problems, but also solutions. The relative balance between problems and solutions is determined, not by the cattle per se, but by human choices about production systems (scale, concentration, control, markets, domination, stewardship, sustainability, or exploitation). The question for Canadian policymakers, farmers, and citizens is not simply "should we have more cattle or fewer?" The proper question is something closer to these lines: how can the numbers of livestock we raise and the ways in which we choose to raise them best move us toward our goal of sustaining the land and all its life in perpetuity?

Livestock systems: A climate-compatible cattle sector

Methane solutions on our farms and in our food systems

We want to maintain the many benefits livestock production brings. Even so, preserving a place for cattle and other livestock in a global civilization colliding with biophysical limits will be difficult. It will require wise, flexible, energetic, concerted action based on evidence and honest, non-ideological analysis. A great many aspects of our current commodity livestock model are incompatible with a stable-climate future. A transformed livestock sector, however, *can* be part of the solution. But transformation is needed.

Here is a brief sketch of the solutions: people who are eating a great deal of meat need to eat less; the planet needs to host fewer cattle; at the same time, however, we need to create systems wherein a smaller number of cattle support a larger number of farmers and underpin sustainable incomes; and we need to ensure that those cattle are raised in enhanced-management systems that maximize soil-building, grassland health, and other ecological benefits.

To attain these goals we must cast aside many aspects of our current meat system: control by mega-corporations; a focus on maximizing production while minimizing farmgate prices; the huge and growing spread between the prices consumers pay for meat and the prices farm families receive; and a food system that turns precious, delicious, high-quality meats into trillions of forgettable drive-through meals, unbalanced and unhealthy diets, and food-induced illness and death. Table 8-1 shows some of our livestock-production aims and how we might achieve these within an emissions-limited world.

Table 8-1. Our livestock production aims and how to achieve them (and how not to)

Goal is to maximize	What is needed	The industry approach
Soil building and enhanced soil-carbon levels	Animals on grass, best-possible grazing management, mixed farms, integrated systems	Animals in huge feedlots; impoverished producers pushed to overgraze
The number of sustainable livelihoods	Many small and medium-sized, dispersed production units, and mixed farms	Specialized mega-operations and concentrated production
Satisfaction and enjoyment from meat consumption	A focus on quality, enjoyment, and nutrition	Maximum production of low-value commodity meats
The supply of food for humans	Animals grazing on non-arable land or forming integrated parts of mixed farming operations	Increased grain feeding in very large production units
The chance of reducing methane	Fewer animals and less meat consumption	More animals and ever-higher consumption around the world
The chance of maintaining the land in perpetuity	Cattle as integral parts of healthy grassland ecosystems and regenerative agriculture	Cattle as feedstocks into a global corporate protein complex

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[52] Lynch et al., "Management of Canadian Prairie Region Grazed Grasslands: Soil C Sequestration, Livestock Productivity and Profitability." *Canadian Journal of Soil Science* 85, no. 2 (2005), 187.

Before we get to these larger, structural changes to the cattle sector, let us acknowledge that there are a host of technical changes farmers can make to their production systems that will lower emissions. Many of these changes are already underway and have been for decades. Many of these changes are just part of farmers becoming “more efficient.

The simplest equation for cattle emissions looks like this:

$$\text{total emissions (kgs)} = \frac{\underline{\text{quantity of beef required (kgs)}}}{\text{beef output per animal(kgs)}} \times \text{emissions per animal (kgs)}$$

The term on the left, “total emissions,” is what is causing problems. The equation shows us that in order to lower emissions tonnage we must:

1. Reduce the quantity of beef required, i.e., reduce per-capita consumption; or
2. Increase beef output per animal, i.e., make the system more “efficient”; or
3. Reduce emissions per animal, e.g., by increasing feed digestibility.

Our emissions problem is now so dire that we will have to do all three. Some changes in Canada’s beef-production system we should consider include:

1. Reduce beef production by 10 to 15% and, by using incentives and other measures, restrain production from rising once margins and prices improve. We can meet Canada’s emission-reduction commitments and stabilize our climate; or we can expand beef production; but we cannot do both.
2. Governments could work with farmers to proliferate a suite of productivity and management BMPs that increase beef output per animal and, hence, reduce the number of animals needed to produce a given quantity of saleable beef. Such practices and BMPs include:
    a. Culling all but the most productive animals. Farmers could be encouraged to remove animals emitting methane and not making adequate contributions to meat production.
    b. Maximizing feed conversion and weight gain rates, thus decreasing age at slaughter. The sooner an animal reaches slaughter weight the lower its lifetime emissions. This can be accomplished by:
        i. Utilizing the best genetics;
        ii. Maximizing the number of healthy calves per cow and maximizing herd health;
        iii. Improving pastures and including high-nutrition, easier-to-digest legumes;
        iv. Maximizing feed availability through enhanced pasture-management practices such as adaptive multi-paddock, mob, or rotational grazing;
        v. Maximizing the efficiency of backgrounding, finishing and feeding; and
        vi. Ensuring that all herds are optimally and innovatively managed, thus advancing the larger project of replacing energy and fossil fuels, land, and other purchased inputs with human management, innovation, and judgment, and with improved soils and the products of healthy, balanced ecosystems.[53]
3. Farmers and governments co-operate to implement BMPs to reduce emissions per animal. These practices include:
    a. Maximizing feed quality and digestibility.

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[53] P. Gerber et al., *Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities* (Rome: UN FAO, 2013), 50, Table C.

b. Examining the environmental, herd health, economic, and consumer-acceptance effects of methane-reducing feed additives such as dietary lipids, enzymes, and probiotic cultures.[54] Governments must facilitate vigorous research into feed additives that can be used by Canada's cow-calf producers. Currently, however, such additives remain wholly unproven and potentially dangerous. Extreme caution is warranted.

c. Proliferating low-emission manure management. As noted in the next section, processes such as composting and manure-methane capture need to be evaluated and, where promising, deployed in order to reduce emissions.

Making these changes could cut Canada's livestock emissions by 20 to 30%. The Food and Agricultural Organization (FAO) of the United Nations writes in a 2013 report that a "30% reduction of GHG emissions would be possible, for example, if producers in a given system, region and climate adopted the technologies and practice currently used by the 10% of producers with the lowest emission intensity. … It should be noted that the mitigation potential is estimated at constant output."[55] The report goes on: "In ruminant production, there is a strong relationship between productivity and emission intensity … emission intensity decreases as [per-animal beef] yield increases."

Non-grazing systems: considerations for feeders and backgrounders and dairy operations

Not all cattle production takes place on grass. In winter, cattle are fed hay and grain. In parts of Canada cattle are fed partly or wholly on grain as parts of "backgrounding" or finishing operations. Dairy cattle are often fed carefully formulated mixes of silage and grains. Getting grazing right solves part of the livestock problem, but to deal fully with livestock emissions we will have to consider grain feeding, too.

When cattle are fed on grain the methane emissions from their stomachs decrease. But the grain itself has a large emissions footprint—from the fuel and fertilizer and chemicals that went into producing it. The same consideration applies to other livestock such as chickens and hogs that are fed on grain. So, in order to reduce the overall emissions from livestock the emissions footprint from the livestock feed supply must be reduced. The other measures in this report—lowering fertilizer use, reducing emissions from tractors, and moving toward low-input production systems—can reduce the emissions associated with a given quantity of feedgrain. Because the emissions from the livestock sector are, to a significant degree influenced by practices in the grain sector, livestock producers have an interest in what is happening those production systems. Low-emission livestock systems require at least three things: low-emission animals, low-emission manure handling, and access to low-emission grain and feed supplies.

Cattle producers have already made strides

Cattle farmers and ranchers have already done a tremendous amount of work to bring down emissions. An important 2015 study published in the journal Animal Production Science compared the environmental footprint of cattle production in 2011 to that of 1981.[56] It found that in 2011, "beef production in Canada required only 71% of the breeding herd (i.e., cows, bulls, calves and replacement heifers) and 76% of the land needed to produce the same amount of liveweight for slaughter as in 1981." When all emissions were counted, including those from the production of feedgrains, etc., producing a kg of beef in 2011 resulted in the emission of 12.0 kgs CO_2e. This compares to 14.0 kgs CO_2e in 1981—a 14% reduction in total GHG

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[54] Gerber, et al., *Tackling Climate Change through Livestock*, 48; K. Satyanagalakshmi et al., "An Overview of the Role of Rumen Methanogens in Methane Emission and Its Reduction Strategies," *African Journal of Biotechnology* 14, no. 16 (2015).

[55] Gerber et al., *Tackling Climate Change through Livestock*, 8 & 46. See also pp. 45-46.

[56] G. Legesse et al., "Greenhouse Gas Emissions of Canadian Beef Production in 1981 as Compared with 2011." *Animal Production Science*, 2015.

emissions for the same amount of beef output.[57] A 2015 study of beef production in Australia similarly found a 14% reduction in the GHGs emitted to produce a kg of beef, comparing 1981 to 2010.[58] And a 2011 study of the US beef production system found a 16.3% reduction in GHG emissions to produce a kg of beef, comparing 1977 to 2007.[59] In all three reports the authors cited several ways in which farmers and ranchers had increased efficiency and productivity: higher weaning weights; increased daily weight gain; increased slaughter weight (e.g., Canadian steer slaughter weights have increased 29%); improved reproductive success and herd health; reduced time to slaughter; increased yields/efficiency in feedgrain production; and "a shift towards high-grain diets that enabled cattle to be marketed at an earlier age."[60]

Creating sustainable livestock systems goes far beyond tweaking the technical aspects of production: bull genetics, feed mixes, weaning weights, finishing rations, etc. Structural change is needed. While emission reduction is vitally important, it must be accomplished while supporting and improving farm profitability. Raising farm incomes increases the resilience of our family farms and their capacities to invest in emissions-reduction measures, best-management practices, technologies, and equipment. Policies or on-farm measures that hurt farmers financially will be massively counterproductive—destroying those farm units' capacities to invest in emission-reduction measures and destroying farmers' goodwill. This cannot be stressed enough: ***in every aspect of GHG emission reduction policy, the first priority of government must be to enhance farmers' financial returns and thereby increase farmers' capacities to make the very substantial investments and changes required to transform the nation's agricultural sector and to cut emissions.*** Because input suppliers, grain companies, beef packers, and others in the agri-food chain have extracted so much wealth from the farm level, our farms are now without the financial reserves they need. Government policies that simply push farmers to invest and change—without taking account of this wealth extraction and the depleted financial state of our family farms—will fail. To succeed, policies to reduce GHG emissions must come as parts of concerted, effective policies to increase net farm incomes.

Livestock systems: Methane solutions elsewhere

The world has a methane problem. That is the bad news. Here is some good news: We can reduce atmospheric methane concentrations and attendant warming. Methane is not like CO_2, which stays in the atmosphere for centuries. No, methane is a "short-lived" gas. On average, it stays in the atmosphere for less than ten years. Most important, many natural processes work to strip it out of the air.

Currently, human and natural sources emit about 558 million tonnes of methane per year, and natural processes in the atmosphere and soils remove all but 10 million tonnes.[61] Despite our huge increase in methane production, sources and sinks are not far out of balance. Therefore, if we stop increasing our emissions and reduce them modestly then atmospheric concentrations could begin to fall. We might see significant declines in just decades. This is not the case for CO_2, which will stay in the atmosphere for centuries. But with methane, we have a real chance of reducing atmospheric levels and, as we do so, moderating warming and slowing climate change.

Emissions from cattle are part of the methane problem. But the problem is magnified by the fact that these ruminant emissions come atop huge plumes of emissions from the energy sector. Natural gas is mostly methane. When our energy companies produce and transport natural gas, a not-insignificant fraction of that methane leaks out. In addition, natural gas, i.e., methane, is often found with oil. Some of that gas is

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[57] Legesse et al., "Greenhouse Gas Emissions of Canadian Beef Production in 1981 as Compared with 2011."

[58] S. Wiedemann et al., "Resource Use and Greenhouse Gas Intensity of Australian Beef Production: 1981–2010," *Agricultural Systems* 133 (February 2015).

[59] J. Capper, "Comparing the Environmental Impact of the US Beef Industry in 1977 to 2007," *Journal of Animal Science* 88 (2010).

[60] Legesse et al., "Greenhouse Gas Emissions of Canadian Beef Production in 1981 as Compared with 2011," A.

[61] Marielle Saunois and 80 coauthors, "The Global Methane Budget 2000–2012," *Earth Systems Science Data* 8, no. 2 (2016).

vented into the atmosphere. These "fugitive" emissions of methane make up a large share of Canada's overall GHG emissions. In Canada, methane emissions from cattle are 24 million tonnes CO_2e per year, but emissions from fossil fuel production are at least 47 million tonnes per year CO_2e[62]—twice as high. (Energy-sector emissions are often under-reported.) This means that cutting energy-related methane emissions by half would yield a reduction equivalent to getting rid of all the cattle in Canada.

Policies focused on minimizing emissions from the Canadian and global fossil-fuel sectors (banning venting and minimizing leaks from drilling and fracking and from pipes and valves) could bring the rate of methane creation below the rate of removal and cause atmospheric levels to fall. This could create emissions space for continued cattle production.

All sectors of the Canadian economy must reduce emissions. It would be irresponsible for Canada's farmers to simply insist that methane-emission reductions should only come from the oil and gas sectors. That said, methane emission reductions from the oil and gas sector will probably be easier, cheaper, and accomplished with no loss of benefits (i.e., no loss of useful productive output) compared to similar reductions pursued in the livestock sector. Put another way, oil and gas can be produced without methane emissions, beef cannot be.

A workable plan for moving forward may include restraining cattle numbers, maximizing herd productivity, propagating grazing BMPs, reducing emissions from cattle to the greatest possible extent, and *focusing on reducing wasteful methane leaks and venting from fossil-fuel production*. A small reduction in global methane emissions from livestock coupled with moderate reductions from the petroleum sector could cause atmospheric methane levels to begin falling—creating (atmospheric) space for sustainable, soil-building grassland farming, mixed farming, cattle grazing and finishing, and delicious and nutritious livestock products. For an excellent overview of methane fluxes, sources, sinks, and balances see recent research by Marielle Saunois and her more than 80 coauthors.[63]

Fewer cattle, less methane, more farmers, higher prices, higher margins

Across Canada and North America, it is probable that modest and gradual reductions in livestock numbers can support higher prices, higher net farm incomes, and perhaps even an increased number of farms with livestock and more farmers overall. How can we have fewer animals yet more livestock farms? By reversing the trends of recent decades. As cattle numbers and beef output have increased, the number of farms with cattle has fallen. Despite increasing output, The Market has terminated *half* of Canada's cattle farms in the past three decades. In 1986, Canada had fewer cattle than it does today and a much lower output in terms of kilograms but the country had *twice* as many farms raising cattle.[64]

The globally dominant livestock packers have increased their profits by pushing farmers to double and redouble production—playing farmers in one region against those in another, promoting oversupply, and moving animals and meat across borders to "discipline" domestic producers whenever prices threatened to rise. Farmers have suffered and disappeared as net incomes fell.

The greatest threat to the economic survival of the Canadian farm families who produce cattle is not the idea that meeting emission-reduction targets may mean modest, gradual reductions in overall animal numbers—perhaps 10 or 15 percent. The greatest threat is a corporate packer- and retailer-controlled system that pushes farmers to produce more, requires consumers to pay more, takes an ever larger share of revenues and profits for the globally dominant corporations, and expels hundreds of Canadian family farm

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[62] Environment and Climate Change Canada, Canada's Official Greenhouse Gas Inventory, http://data.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/

[63] M. Saunois et al., "The Global Methane Budget 2000–2012," *Earth System Science Data* 8, no. 2 (2016).

[64] Statistics Canada Table 32-10-0155-01 (formerly CANSIM 004-0004).

cattle producers from the sector each and every year. Citizens, cattle farmers, and governments now need to work together to reduce cattle-related emissions, *but also to restore balance and farmer profitability within the system*. The trend of the past 30 years—the rapid expulsion of cattle farmers—can be reversed. The corporate-controlled cattle-industrial complex must be dismantled.[65] In its place we must build a farmer-focused cattle-ecological collaboration.

Action	**Restructure the cattle sector so that fewer animals support more farms and higher net incomes. Curb corporate power and profiteering and replace the cattle-industrial complex with integrated systems that maximize financial, social, and environmental benefits.**
Action	**Propagate best-possible grazing techniques to maximize carbon gains, build up soils, and support the health of sustainable grassland ecosystems**
Action	**Reduce methane emissions from cattle by proliferating best-possible husbandry and stewardship, increasing efficiency, and reducing the number of animals.**
Action	**Cut emissions from the oil and gas sector to create atmospheric space for food production, including ruminant livestock and rice paddy agriculture.**
Action	**Embrace regenerative agriculture: grazing and mixed-farming systems that utilize natural nutrient cycles; diverse animal and plant mixes; careful, sensitive management; and best-possible grazing methods to restore and improve soils, protect water, enhance biodiversity, and support sustainable livelihoods.**
Action	**Make livestock rearing part of a move toward our goal of sustaining the land and all its life in perpetuity.**
GHG Savings	Significant percentages of agricultural and energy-sector emissions. Atmospheric methane levels could begin to fall.
Costs	To be calculated. Moving a few percentage points of revenues from the balance sheets of packers and retailers to farmers would fully pay for all on-farm costs.
Co-benefits	Healthy soils, grassland ecosystems, more farmers, increased rural prosperity, farm families seen as climate-solution leaders.
Problems	Meat-packing-company resistance.
Start	Immediately.
Completed	Ongoing, but with significant progress by 2030.

Livestock systems: Manure

Promising measures to reduce emissions from manure include composting; sealed manure-storage units with biodigesters that collect methane and use it to produce heat or electricity; changing storage methods (e.g., dry vs. wet storage); shorter storage times; etc. The table below, copied from the UN report *Tackling Climate Change Through Livestock* gives a sense of the many options. Canadian-based experts have done extensive research on manure handling and application. It is beyond the scope of this report to review the voluminous research on hand or to detail the many ways that improved manure collection, storage, and application can reduce emissions. Nonetheless, it is critical that governments and scientists identify the

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[65] For information about packer and retailer power in the livestock system, see: NFU, *The Farm Crisis and the Cattle Sector: Toward a New Analysis and New Solutions* (Saskatoon: NFU, 2008), https://www.nfu.ca/wp-content/uploads/2018/05/LivestockreportFINAL.pdf

most promising measures so that manure-related emissions—about 10% of total Canadian agricultural emissions—can be rapidly and significantly reduced.

Table 8-2. Manure-handing techniques to reduce emissions

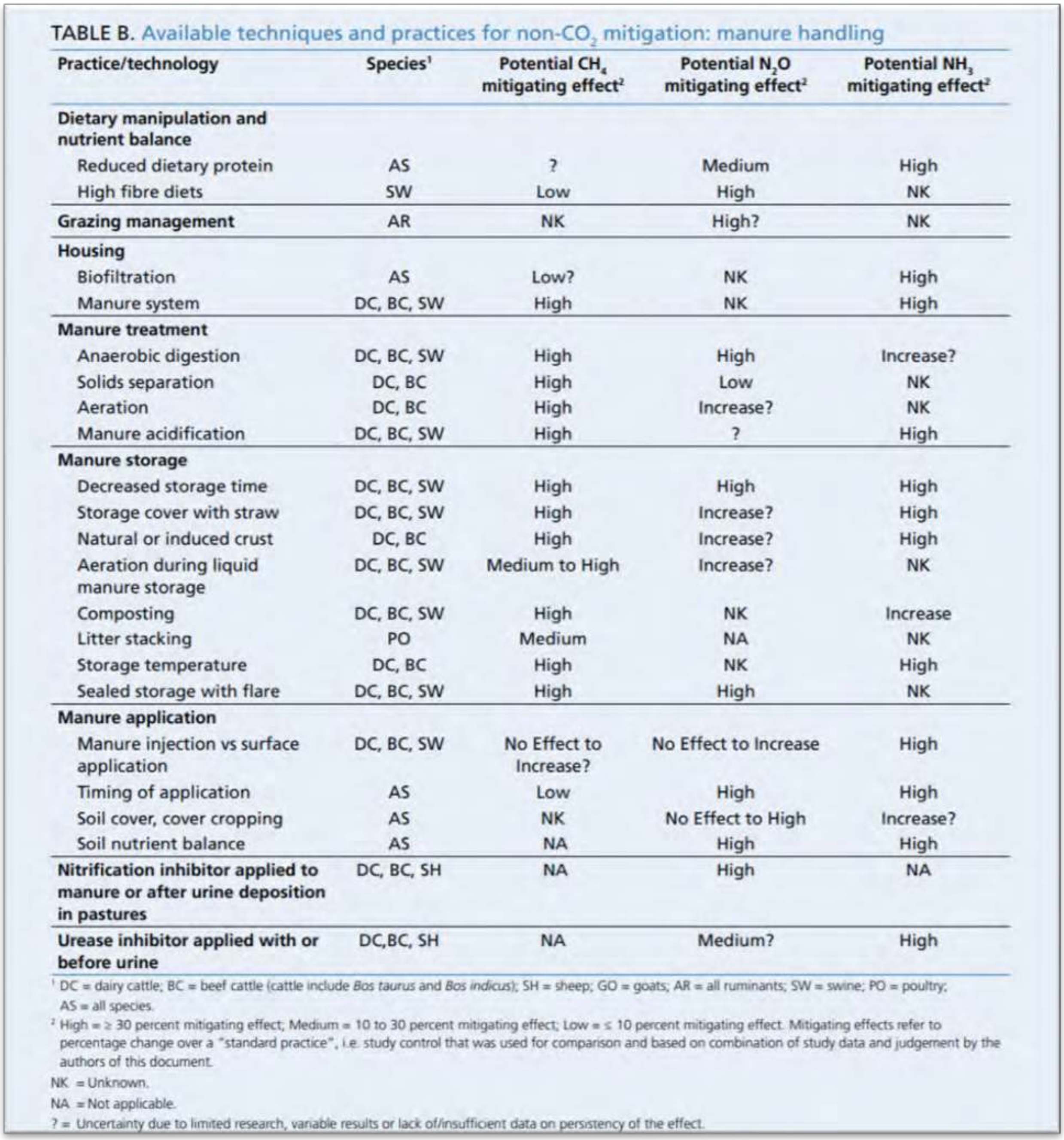

TABLE B. Available techniques and practices for non-CO_2 mitigation: manure handling

Practice/technology	Species[1]	Potential CH_4 mitigating effect[2]	Potential N_2O mitigating effect[2]	Potential NH_3 mitigating effect[2]
Dietary manipulation and nutrient balance				
Reduced dietary protein	AS	?	Medium	High
High fibre diets	SW	Low	High	NK
Grazing management	AR	NK	High?	NK
Housing				
Biofiltration	AS	Low?	NK	High
Manure system	DC, BC, SW	High	NK	High
Manure treatment				
Anaerobic digestion	DC, BC, SW	High	High	Increase?
Solids separation	DC, BC	High	Low	NK
Aeration	DC, BC	High	Increase?	NK
Manure acidification	DC, BC, SW	High	?	High
Manure storage				
Decreased storage time	DC, BC, SW	High	High	High
Storage cover with straw	DC, BC, SW	High	Increase?	High
Natural or induced crust	DC, BC	High	Increase?	High
Aeration during liquid manure storage	DC, BC, SW	Medium to High	Increase?	NK
Composting	DC, BC, SW	High	NK	Increase
Litter stacking	PO	Medium	NA	NK
Storage temperature	DC, BC	High	NK	High
Sealed storage with flare	DC, BC, SW	High	High	NK
Manure application				
Manure injection vs surface application	DC, BC, SW	No Effect to Increase?	No Effect to Increase	High
Timing of application	AS	Low	High	High
Soil cover, cover cropping	AS	NK	No Effect to High	Increase?
Soil nutrient balance	AS	NA	High	High
Nitrification inhibitor applied to manure or after urine deposition in pastures	DC, BC, SH	NA	High	NA
Urease inhibitor applied with or before urine	DC,BC, SH	NA	Medium?	High

[1] DC = dairy cattle; BC = beef cattle (cattle include *Bos taurus* and *Bos indicus*); SH = sheep; GO = goats; AR = all ruminants; SW = swine; PO = poultry; AS = all species.

[2] High = ≥ 30 percent mitigating effect; Medium = 10 to 30 percent mitigating effect; Low = ≤ 10 percent mitigating effect. Mitigating effects refer to percentage change over a "standard practice", i.e. study control that was used for comparison and based on combination of study data and judgement by the authors of this document.

NK = Unknown.

NA = Not applicable.

? = Uncertainty due to limited research, variable results or lack of/insufficient data on persistency of the effect.

Source: copied from P. Gerber et al., *Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities* (Rome: UN FAO, 2013), 49.

Action	**Research, select, and rapidly implement initiatives to reduce manure-related emissions.**

Chapter 9: Other Necessary Policies and Measures

Other policies and measures: Alternative Land Use Services (ALUS) and farmland set-aside programs

Several North American programs have functioned to set aside fragile, marginal, or ecologically valuable farmland. The US has its Conservation Reserve Program (CRP); Canada had its Greencover Canada Program.[66] Support is now growing for the widespread adoption of a new program, called Alternative Land Use Services (ALUS), to transition ecologically important or sensitive agricultural lands into wetlands, forest, and other conservation or restoration uses.

Set-aside programs have two climate change mitigation effects. First, they reduce fuel- and fertilizer-related emissions as agricultural activities cease on that land. Second, set-asides are part of a *systematic* approach to reducing emissions in that they help to actually achieve emission-reductions from efficiencies. Without set-aside, emission-reduction measures—many of which create "efficiencies"—may just lead to higher production and emissions. For example, enhanced grazing techniques can reduce emissions and speed soil-carbon gains, but such programs also enable *higher stocking densities* and, hence, higher cattle numbers and emissions. The solution is to take some of the land that higher stocking densities can free up and transfer it into set-aside programs, *especially those that encourage tree planting, afforestation, or wetlands restoration*. Similarly, without set-asides, techniques such as 4R fertilizer management may simply lead to higher production and higher emissions. Set-aside programs create emission-reductions on their own, and they *integrate* with and support other measures and policies to reduce emissions.

As much as possible and where appropriate, set-aside programs should incentivize farmers to plant trees: reforestation, afforestation, shelterbelts, hedgerows, or riparian strips. Wetland creation or restoration is another option. **If Canada's agricultural systems can increase forested and wetlands areas while maintaining adequate production levels and maintaining or increasing farm income and farmer numbers then it is likely that we will have taken important steps toward successful climate change mitigation.** By setting aside 5 to 10% of cropland (5 to 10 million acres), Canada could reduce agricultural emissions by 5 to 10 percent. Assuming an incentive payment of $40 per acre per year the cost would be $200 to $400 million annually—a fraction of the cost of current farm-support programs. Note that effective set-aside programs assume that farmland area is capped, i.e., acres enrolled in set-aside programs will not be offset by new farmland created elsewhere—from forests, wetlands, marginal land, etc. Provincial policies should cap farmland area and protect wetlands, treed areas, and forests.

Action	**Set aside 5 to 10% of Canada's farmland.**
GHG Savings	5 to 10% of current agricultural emissions.
Costs	$200 to $400 million annually to governments.
Co-benefits	Increased soil carbon and organic matter, erosion control, water purification, wildlife habitat, and enhanced biodiversity.
Problems	Crop production may decline slightly.
Start	More than 5% of Canada's farmland base enrolled by 2025.
Completed	Ongoing, but with significant progress by 2030.

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[66] Agriculture and Agri-Food Canada, "Greencover Canada's Land Conversion Component: Converting Environmentally Sensitive Land to Perennial Cover." (Regina: AAFC, 2003); Agriculture and Agri-Food Canada, "Greencover Canada: Technical Assistance Component Project Summary" (Ottawa: AAFC, 2007), www5.agr.gc.ca/resources/prod/doc/pdf/gcrtac_rpt_nov07_e.pdf

Other policies and measures: A Super-PFRA to support alternative land uses and protect soil and water

In the 1930s, farmers in parts of North America were battered by a multi-year drought unprecedented in the post-settlement period. This led to the creation, in 1935, of Canada's Prairie Farm Rehabilitation Administration (PFRA). The PFRA was mandated to "…secure the rehabilitation of the drought and soil drifting areas in the Provinces of Manitoba, Saskatchewan and Alberta, and to develop and promote within those areas systems of farm practice, tree culture, water supply, land utilization, and land settlement that will afford greater economic security…."[67] It is a historic irony (or tragedy) that on the eve of worsening impacts of climate change, Canada's federal government chose to dismantle the PFRA.

Support is needed for provincial governments and farmers in their actions to protect our farms, fields, soils, waterways, water supplies, trees, wetlands, and food-production capacities against the impacts of climate change. To provide that support, and as a core part of the *mobilization of near-wartime intensity* outlined above, it is necessary to create a new PFRA—a *super PFRA* that will operate all across Canada and help coordinate emission reductions and adaptation and preparations for climate change. A super PFRA could provide the trees for the afforestation efforts listed above; it could engineer and supervise wetlands creation over tens-of-thousands of hectares; it could work with farmers on water efficiency and water supply projects; it could support work on monitoring agricultural GHG emissions and assist in *evaluating measures to reduce those emissions*; and it could take significant responsibility in developing programs to ensure that Canadian soils and farmland are protected from the coming ravages of climate change. A multi-year drought in the 1930s created a need for a PFRA; the climate change impacts now poised to strike create double the need today for an expanded and modernized agency in the mold of the PFRA. The new agency should be Canada-wide and have an enlarged mandate and budget. Perhaps it could be called the Canadian Farm Resilience Administration—the *CFRA*.

Action	**Create a Canadian Farm Resilience Administration (CFRA), to protect soils, farmland, water, and our food-production capacities; support moves toward alternative land use, including wetlands and afforestation; and assist in the mobilization needed if we are to have a chance of meeting our emission-reduction targets and stabilizing our climate**
GHG Savings	Supportive of other initiatives.
Costs	Very roughly, maybe $150-$200 million annually Canada-wide—about $1 per acre of farmland.
Co-benefits	A more beautiful and biodiverse countryside. Slowing extinctions and reversing habitat loss.
Problems	None.
Start	2020
Completed	Ongoing

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[67] Government of Canada, Legislative Services Branch, "Prairie Farm Rehabilitation Act, Consolidated Federal Laws of Canada" (2002), http://laws-lois.justice.gc.ca/eng/acts/P-17/page-1.html.

Other policies and measures: A carbon-tax-and-refund system

While Canada's carbon tax debate shows there is a lack of consensus on whether and how that tax should be applied, particularly in the agriculture sector, *farmers should not reject carbon taxes out of hand.* Rather, farmers should engage in discussions on how an agricultural carbon-tax-and-refund might best be structured. As a contribution to that discussion and toward creating a carbon-tax-and-refund system that can support the aspirations and incomes of farmers, our organization offers the following.

It is in farmers interests to work with governments to design a carbon-tax-and-refund system that not only reduces on-farm emissions, but increases net incomes. How can this be done? First, such a tax must embody the realities of the farm sector, especially the imbalance in market power between farmers and agribusiness giants. Because of this imbalance, farmers will be forced to pay nearly all the carbon taxes in the food system, including any taxes levied on natural gas to make fertilizer or energy to make steel for machinery. *Any carbon taxes levied on farm input makers will be passed forward to farmers in the form of higher input costs, and any taxes levied on truckers, railways, processors, etc. will be passed back to farmers in the form of lower farm-gate prices.* Farmers will pay it all. An exemption for on-farm energy use will be little help. ***A properly designed carbon-tax-and-refund system could collect taxes from farmers and from input makers, transport companies, processors, etc. and then refund 100% of that money to farmers, in recognition that farmers will be the ultimate payors of all taxes collected up and down the agri-food chain.***

Another consideration is that carbon-tax rates must eventually rise to high levels. Current tax rates—$20 per tonne rising to $50—work out to just a few cents per litre of diesel fuel or gasoline. No one will make large changes or large investments to avoid such small costs. To change behaviours and help achieve our emission-reduction targets, carbon taxes must rise well above $100 per tonne. If taxes rise this high, farmers and other citizens will not be able to afford to pay unless all the tax money is refunded.

The third reason why all carbon taxes paid by farmers must come back to them is that agriculture is export dependent. Farmers cannot shoulder new taxes that international competitors may not face. Refunding all taxes collected solves the export-competition problem.

For the preceding reasons, *100% of carbon taxes collected—at both the farm level and the input-manufacture level—must be refunded to farmers***.** Such refunds would not, however, be based on the amounts each farmer paid. Rather, refunds would be spread proportionately across the farming sector, perhaps paid back to farmers on the basis of gross margins.[68] Farmers would pay taxes based on the carbon emissions related to their operations, but all farmers would receive carbon-tax refunds based on the relative size and production of their farms, as represented by the proxy of gross margins. An independent accounting firm could certify that 100% of tax dollars collected by the government was returned to farmers.

Refunds will be roughly proportional to farm size/revenues, but taxes will be collected based on emissions tonnage. This means that farmers who do the right things (e.g., reduce input use, employ organic or holistic techniques, or invest in equipment to use nitrogen fertilizer more efficiently) will come out ahead financially—their refunds will be larger than the taxes they pay. But farmers who use quantities of fuels and fertilizers that are above average for a farm of their size may come out behind. An agricultural carbon-tax-and-refund system will serve as a strong incentive to economize on energy, pursue efficiency, explore alternatives, minimize fossil-fuel-intensive inputs, and reduce emissions.

There are two remaining reasons why farmers should not, out of hand, reject a carbon tax. First, it is unlikely that farmers will be successful in arguing for carbon-credit payments if farmers push for an

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[68] Gross margins equal net sales minus eligible expenses; i.e., revenues from selling crops, livestock, and other farm products minus direct variable input costs: seed, fertilizer, pesticides, fuel, feed, twine, veterinary medicines, etc.

exemption from economy-wide carbon taxes. The idea that farmers should be paid for sequestration but not pay for excessive emissions seems an untenable position.

Another reason why farmers should not reject a carbon tax is that there are few alternatives. Those who argue against carbon taxes rarely divulge their preferred options. What measures do they advocate to halt agricultural-emission increases and spur reductions in the range of 30% by 2030? Regulations? Prohibitions? If not a tax, what? Quotas? Rationing? Restrictions?

Finally, by incentivizing lower input use and alternatives, carbon taxes can help *increase* net farm income. High-input agriculture has led us to a situation in which input-selling agribusiness transnationals capture 95% of farm revenue. Ongoing farm income problems (including $106 billion in farm debt) are largely a result of wealth extraction by powerful agribusiness corporations. Farmers have two problems: high emissions *and high costs*. Curbing input use can help solve both. It is worth considering that perhaps a carbon tax-and-refund system can help reduce input use, reduce emissions, increase incomes, refocus agriculture, and preserve farms.

Action	**Governments must engage with farmers to collaboratively develop a carbon-tax-and-refund system that farmers can support and that increases our net incomes.**

Tax shifting in the economy as a whole

Excise or “sin” taxes are simple and effective. Governments apply excise taxes to products such as tobacco and alcohol to increase their prices and reduce consumption. Taxing something is a powerful way to reduce demand. This suggests a question: What is taxed most heavily in Canada? The answer: workers. Income taxes and other payroll deductions can act like an excise tax, reducing demand for employees.

Imagine a factory owner who wants to expand production. He or she has at least three options: buy more machinery, use more energy to run existing machinery, or hire more workers. If the owner buys a machine, he or she will have to pay for the machine, plus modest federal or provincial taxes—maybe 5 to 10%. If the factory owner instead purchases more energy—electricity or fossil fuels to drive factory machinery faster or longer—he or she will have to pay the cost of that energy, plus some taxes. While taxes on motor fuels are high, taxes on natural gas and other fuels used “off road” and on electricity are low. The third option is to hire workers. If the factory owner does so, he or she will have to pay wages sufficient to cover workers’ costs of living, plus significant additional amounts so that the workers can pay federal and provincial income taxes, employment insurance and pension contributions, and perhaps healthcare or accident-insurance costs. There is nothing wrong in any of this; it is simply the way we fund the Canadian State—by taxing income from employment and other sources. Progressive income taxes can redistribute income and compel those who gain the greatest income benefits to pay the most back through taxes. But note the excise-tax effect. The factory owner faces a small tax if he or she buys a machine, a moderate tax for energy to run those machines, but the largest tax is payable if he or she adds a worker. We have placed a demand-reducing tax on the thing we want to maximize: jobs and employment. We have created a tax-system incentive for employers to replace workers with machines and fuels. This is not what we want. Faced with declining employment prospects and the need to reduce energy consumption and emissions the solution is clear: begin to shift taxes off workers and on to non-renewable, carbon-emitting energy use. Carbon taxes can be a form of “tax shifting”—a way to shape our economy, protect our environment, and even increase employment. Increase taxes on things you want people to demand less of (fuels, unrecycled paper, single-use plastic, etc.) and, in equal proportions so that the tax shifts are “revenue neutral,” reduce taxes on things you want to increase demand for (workers, etc.).

As a final point it is worth noting that tax subsidies to the energy sector serve as a negative excise tax—a financial incentive that makes energy cheaper and acts as a de facto policy to increase demand and use.

Chapter 10: A Government-Led Mobilization for Transformation

What is needed is a government-led mobilization for the transformation of our energy, food, transportation, and manufacturing systems

Government: The need for strong leadership

If we fail to act immediately and aggressively to curb emissions and stabilize our climate we will permanently destroy humanity's future.

Because we have delayed so long, the scale of required action is now enormous. What is needed is a near-WWII level of mobilization and action. What is needed is a government-led *mobilization* for the *transformation* of our energy, food, transportation, and manufacturing systems—and many other aspects of our societies and economies.

All parties—farmers, citizens, businesspeople, public servants, and government leaders—will have to work hard, continuously, and in respectful co-operation if we are to meet our goals of cutting economy-wide emissions by 30% in a decade and by much more in three decades and cutting agricultural emissions by similar amounts over similar periods.

Consider our food system today. Canada's food-production, processing, and distribution systems are among the highest emitting, most energy-intensive in the world. Canadians are part of a North American food system in which, for every Calorie we eat, we expend *13.3 Calories* of energy, mostly from fossil fuels.[69] Granted, this measure is for *the food system as a whole* and takes into account, for example, the fact that 30 to 40% of all produced food is wasted.[70] It takes into account the senseless toing and froing of food in an irrational global food transport system that often maximizes food miles. It takes into account the fact that feeding grain to hogs or cattle turns 5 or 10 Calories of grain into 1 Calorie of pork or beef. And it takes into account the fact that 2,100 calories, mostly from fossil fuels, are required to make a can of diet pop (can included) though that pop delivers just 1 Calorie of food value.[71] It is increasingly clear that our planet can no longer afford to host such an inefficient, irrational, and emissions-maximizing food system.

Modest adjustments, increased efficiency, and high-tech add-ons will not be enough. There are deep and profound *structural* problems within our food systems—problems that manifest in outsized GHG emissions, extinctions and biodiversity loss, ocean dead zones, record high farm debt, often-negative net farm incomes, aging farm populations, decimated rural communities, ever-longer food transport distances, and a host of other social, economic, and environmental pathologies. It will not be enough to merely tinker. Our farm and food systems must be reimagined and restructured. We must proceed with swing-for-the-fence levels of ambition and governments must lead the way.

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[69] Calculated using 2007 data, but likely accurate for later years. See Patrick Canning et al., *Energy Use in the U.S. Food System* (Washington, D.C.: USDA, 2010), pp. 3 & 12, http://www.ers.usda.gov/media/136418/err94_1_.pdf. Canning et al. estimate that total US energy use in 2007 was 100 quadrillion BTUs and that 15.7% of this was utilized in the food system. These number forms the energy input side of the 13.3:1 ratio. The other side of the ratio, the calorie output side (i.e., per capita consumed calories) comes from United States Department of Agriculture, *Agriculture Fact Book 2001-2002* (Washington, D.C.: USDA, 2003) p. 14.

[70] M. Gooch, A. Felfel, and N. Marenick, "Food Waste in Canada," *Value Chain Management Centre, George Morris Centre*, 2010; M. Gooch and A. Felfel, "'$27 Billion' Revisited: The Cost of Canada's Annual Food Waste," 2014; D. Gunders, "Wasted: How America Is Losing up to 40 Percent of Its Food from Farm to Fork to Landfill," *Natural Resources Defense Council*, 2012.

[71] David Pimentel and Marcia Pimentel, *Food, Energy, and Society*, 3rd ed. (Boca Raton, FL: CRC Press, 2008).

Government: Setting targets & beginning to act, but more is needed

Governments are beginning to take actions. They are making commitments, signing treaties, setting goals, implementing modest carbon tax-and-refund systems, and incentivizing electric vehicles.

Though governments have led with goals and targets and some initial programs, governments often seem to lack convictions, capacities, and coherent direction. Among federal and provincial ministers and departments it appears that there exists a huge and potentially disastrous underestimation of the extent of the challenges we face. In Ottawa and every provincial capital, there is slow movement where there should be rapid advance. There are understaffed, underfunded environment and climate change departments where there should be bustling and effective management structures with access to the latest technologies and data. There are unanswered questions and half-formed understandings where there should exist clear, ambitious plans and well-developed capacities to implement those plans. There is lethargy where there should be urgency, foot-dragging where there should be leadership. The transformation of our societies and economies necessary to save us from the ravages of catastrophic climate change will require an almost unprecedented effort—a wartime-like mobilization of workers, resources, ideas, vision, leadership, innovation, commitment, and courage. Such readiness is wholly and woefully absent.

If we are to save ourselves we must mobilize. Governments must hire the brightest, most ambitious young minds from our universities and technical schools: tens-of-thousands of engineers, administrators, chemists, biologists, climatologists, agrologists, communications experts, educators, economists, even historians, anthropologists, and political scientists. In Canada's agricultural sector, hundreds of research and demonstration farms are needed. Thousands of agricultural extension workers are needed to help farmers understand and implement the transformative changes required of them. We need thousands of people to measure GHG emissions from various aspects of farming, carbon levels in soils, and the effectiveness of innovative new practices and technologies. We need rapid, up-to-date data collection and publication so that farmers and governments can understand, in near-real-time, the emission and net-income effects of the many changes we will need to make.

Provincial and federal governments must act with unprecedented vigour: expand their capacities, accelerate their actions, and act as they would in the case of an emergency, natural disaster, or military attack. This report is farmers' contribution to the creation of a plan, and farmers' commitment to acting as partners with governments and all citizens in the rapid and complete mobilization that must occur if we are to prevent ecological catastrophe, massive financial losses, and the possible destruction of organized civilization.

Government: Canada's failure to act

Figure 10-1 shows Canada's various international commitments to reduce GHG emissions: Kyoto, Copenhagen, Paris, etc. It also shows how we have already missed, or seem likely to miss, all of those targets. In 2017, the most recent year for which data is available, Canada had near-record high fossil fuel use and CO_2 emissions. A mobilization to fight climate change is not visible. To the contrary, if the war analogy is apt, our governments and their corporate allies appear to be fighting for the other side.

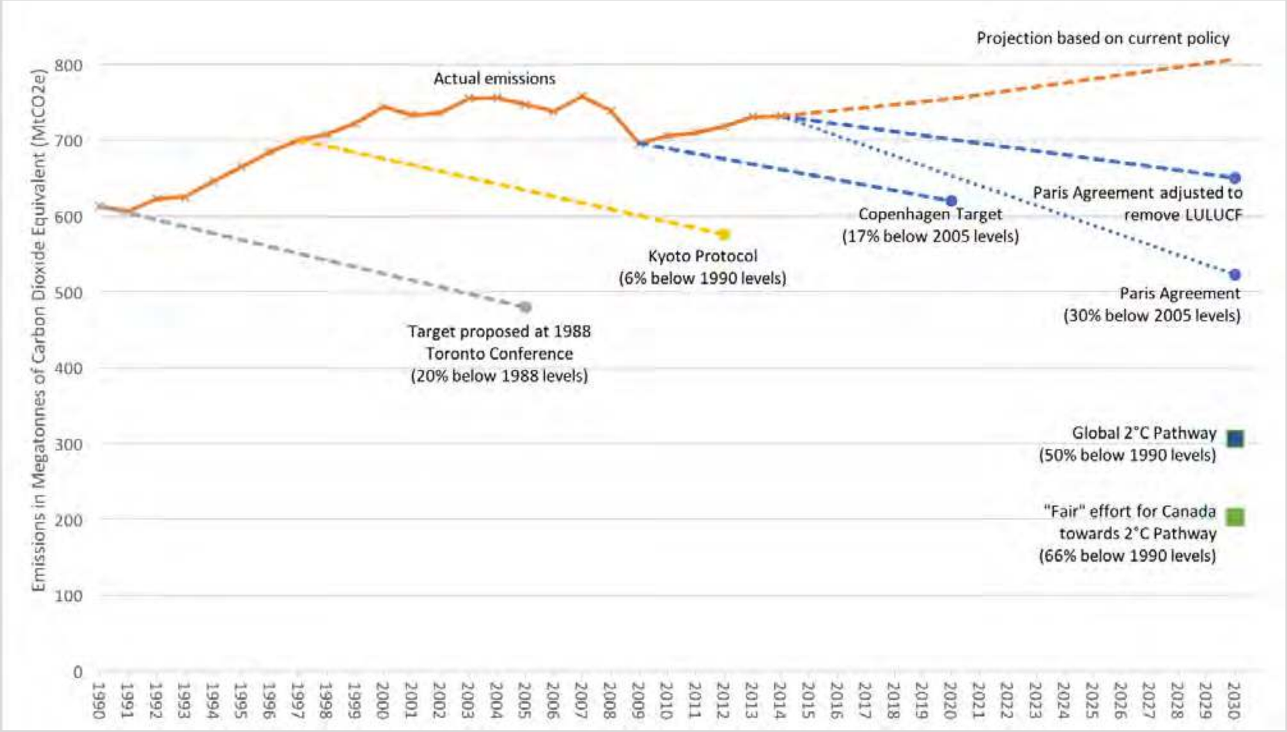
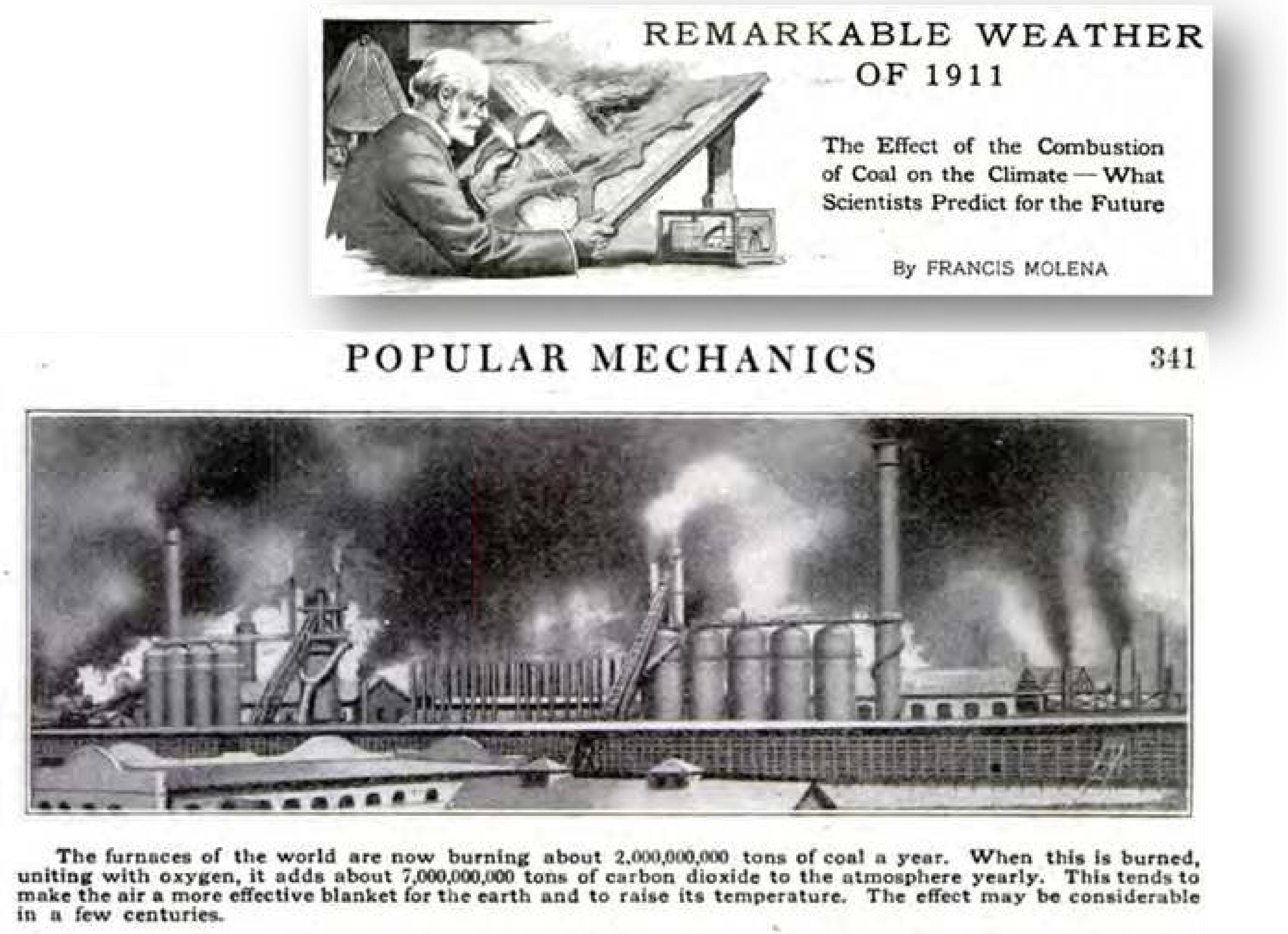


Figure 10-1. Canada's international commitments to reduce CO_2 emissions, vs. actual and projected emissions
Source: Copied, with permission, from Steve Easterbrook, "Missing the Target: Canada's Deplorable Record on Carbon Emissions," blog post, Oct. 18, 2016, https://www.easterbrook.ca/steve/2016/10/missing-the-target-canadas-deplorable-record-on-carbon-emissions/

Such delay is shameful, perhaps criminal. Information about rising GHG levels and temperatures has been available for decades. More than 30 years ago, in 1988, Canada hosted one of the first major international conferences on climate change: "Our Changing Atmosphere: Implications for Global Security." Then-Prime Minister Brian Mulroney, a Conservative, was a driving force behind that conference. It produced a consensus document that stated: "Humanity is conducting an unintended, uncontrolled, globally pervasive experiment, whose ultimate consequences are second only to global nuclear war." Also in 1988, the UN set up its Intergovernmental Panel on Climate Change (IPCC). The IPCC has issued five comprehensive assessments comprising tens-of-thousands of pages. Twenty years ago, Canada and other nations negotiated the Kyoto Protocol which included binding commitments to reduce GHG emissions by 5% below 1990 levels by 2012. Of course, Canada missed its target. Most shameful, of the 191 nations that ratified the Protocol, only Canada has renounced its commitments and exited the process. We have been talking and negotiating and studying for more than 30 years.

Even more revealing, as Figure 10-2 shows, detailed knowledge about fossil fuels and the effects of GHG emissions goes back more than a century.



REMARKABLE WEATHER
OF 1911

The Effect of the Combustion
of Coal on the Climate — What
Scientists Predict for the Future

By FRANCIS MOLENA

POPULAR MECHANICS 341

The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

Figure 10-2: Screen capture of pages from *Popular Mechanics*, March 1912
Source: Copied from Francis Molena, "The remarkable weather of 1911," *Popular Mechanics*, March 1912, https://books.google.ca/books?id=Tt4DAAAAMBAJ&lpg=PA37&dq=Popular%20Mechanics%20march%201912&pg=PA339#v=onepage&q&f=false

The text next to the photo talks about "the effect of the combustion of coal on the climate" and notes that "the furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, united with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature." This clear, concise analysis is now 107 years old.

We have understood the threat of climate change for a long time. But rather than pouring water on the climate change fire, we have poured gasoline. Since 1990, Canada has increased its emissions by 20%,[72] and Canada's farms have increased their emissions by an equal amount. Continued movement in the wrong direction, or slow movement in the right direction, begs ruin.

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[72] Environment and Climate Change Canada, "National Inventory Report 1990-2014: Greenhouse Gas Sources and Sinks in Canada: Part 3" (Environment and Climate Change Canada, 2016).

Chapter 11: Conclusions

We are embarking upon a civilizational transformation.

A fluid future

The past 30 years have been fast-changing and hard to predict: the creation of the internet; the fall of the Berlin Wall; the rise of China; the destruction of the twin towers; the Wall Street collapse; smartphones; etc. So, too, will be the next 30 years. In evaluating the plans contained in this report, please keep in mind that some things we take for granted may be about to change profoundly. It is impossible to know which aspects of our societies and economies will change and which will stay, at least partly, the same. The following are speculative examples. On considering these scenarios, however, we may gain important perspectives.

As the world works to cut greenhouse gas emissions by a third, half, then more, will it be able to maintain the economic growth rates that have prevailed since WWII? The average rate of growth in the global economy over the past decade (2010-2019) was roughly 3%. Continuing that rate of compound growth for 100 years would lead to a global economy 20 times larger than the economy of today. This would not be unprecedented: the global economy of 2018 was 20 times larger than 100 years before. Is a further twentyfold increase possible? Can we bend the emissions curve sharply downward even as economic growth arcs skyward? Can an economy 10 or 20 times as large as ours emit half as much? And if we are forced to curb or abandon economic growth, what will this mean to all other aspects of our society?

To give another example of potential change: Will our late-20th-century project of economic globalization and trade maximization continue if shipping, rail transport, and air travel are curtailed? (Passenger air travel today totals about 7 trillion passenger kilometres[73] annually and goods transport totals about 122 trillion tonne-kilometres.[74] Continuing to move people, products, and commodities on this scale vetoes a stable climate. For decades, Canada and other nations have sought to maximize their food exports. Over the past 30 years, Canadian agri-food exports have risen 6-fold, to approximately $58 billion. Imports have risen even faster. We have worked at the highest levels to create an increasingly far-flung food system—one that *maximizes* food miles. Can this continue as we strive to reduce GHG emissions by a third, by half, and then to nearly zero? Is it possible that climate impacts plus the need to slash emissions render the current farming, food, and global trading systems impossible? Perhaps so. Perhaps not. But such questions demonstrate just how far we must open our minds and stretch our imaginations as we attempt to plan for what will certainly be a very different future. This is what we must consider when we contemplate "transformation."

To give a third example of the potential fluidity of our future: the underpinnings of our economies and patterns of employment (and unemployment) may shift. If western Canada is forced to curtail its economic overdependence on oil and natural gas extraction the question then becomes: what will the millions of people who live in that region do for a living? This raises other issues and questions. In such a society, it may no longer be efficient and desirable to structure agriculture to replace workers and farmers with

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[73] www.darrinqualman.com, " Too much tourism: Global air travel and climate change," https://www.darrinqualman.com/global-air-travel-climate-change/ .

[74] www.darrinqualman.com, "Fraught freight: trade agreements, globalization, and rising global freight transport," https://www.darrinqualman.com/global-freight-transport/ .

energy and energy-intensive machinery and technologies. It may no longer make sense to continue pushing young people out of farming until only 1% (or less) of the population produces food. Perhaps in an emissions-constrained future it may be a good idea to multiply the number of people on the land—to perhaps 4 or 6% of our national population. For most of the past 10,000 years, more than half the people on Earth were farmers.[75] In Canada today, less than 2% are. It is unlikely that we will go back to a situation where half of us farm, but we should remain open to the idea that the optimum proportion may be higher than one-fiftieth.

It is also important to keep in mind the potential for smaller but no-less-important changes. As Canada continues to warm, the area where farmers can grow corn and soybeans will expand. This means that even as we change our farms to cut emissions, and even as climate impacts force other changes upon us, we may be growing different crops with different equipment using a different mix of inputs and delivering those crops to different locations or markets.

Just as Canadian agriculture was profoundly different in 1950 than in 1919, agriculture in 2050 will be profoundly different than in 2019. The future will not be like the present, nor like the recent or distant past. It will be very different from anything that has gone before, either because we have taken steps to transform our petro-fuelled, high-emissions, globalized society and economy into one that protects the climate and our future; *or because we have not*, and, as a result, we have become battered, immiserated, destabilized, and impoverished by a violent and destructive mother nature—one radicalized as a result of our emissions extremism.

Although transformative change to cut emissions and stabilize our climate brings risks, it also opens the way for rewards. The necessary changes ahead bring the possibility of refocusing of our farm and food systems—away from the push to increase production, exports, and trade and toward increasing farm profits and stability and the number of people on the land taking care of the soil, water and other species. **We are looking at a future wherein agriculture must increasingly re-merge with nature and culture to create a much more integrated, life-sustaining, and community-sustaining agroecological model of human food provision, nutrition, and health.** So, in reading this report, do not imagine the current world with some emissions-lowering techno-tweaks or some shelterbelt-planting incentives. Imagine a transformed world. This report is a provisional roadmap to begin to navigate that transformation.

This report looks several decades into the future: to 2030, 2050 and beyond. Its starting point is the farm and food systems we have. But it also looks at the farm and food systems we *want*. It considers the transformations that must occur as we redesign agriculture to reduce GHG emissions by half. And it asks us to stretch our minds to imagine how these necessary transformations can underpin a larger and very positive transformation of our farms, food systems, communities, and economy. **The changes that we *must make* open the door for changes we *want to make*.**

Compare our comprehensive, ambitious plan to similar plans

Transforming agriculture in ways that reduce energy use and greenhouse gas emissions by half will not be easy. Some of the measures recommended in our plan are costly; some are difficult; others are disruptive or unpleasant; many will be controversial. Many of our proposals challenge the ways that farmers have been farming for years. There is no cheap, easy, and wholly pleasant way to restructure agriculture and the larger food system to cut emissions and energy use, to transition new energy sources, and to transition to new practices, new crops, and new patterns of production. Change is hard. But change is necessary. And though many of these changes will seem daunting, farmers must remember that they will be phased in over

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[75] Fernand Braudel, *The Structure of Everyday Life: The Limits of the Possible*, vol. 1 of Civilization and Capitalism 15th–18th Century, trans. Siân Reynolds (New York: Harper and Row, 1979), 49.

decades. And farmers must remember how much they have changed their operations in recent decades. Farming in 2019 is different than in 1989. Gone today are most of the discers, the 50-pound bags of fertilizer, and rural landscapes checkered with summer fallow. Gone are most of the small square bales and many of the open tractors circling the fields. Today, many farmers direct-seed with air drills, some let satellite-guided computers steer their tractors or combines, many check weather or prices on smartphones, some even check cattle or crop conditions with drones, others milk with robots. Other farmers are using new grazing techniques, organic methods, or serving local or high-value markets. Even if there was no climate change threat, agriculture would change profoundly in coming decades, as it did in the preceding ones.

In evaluating the plan laid out in this report, it is important that farmers and policymakers compare it, not to the cost and difficulty of half-measures or maintaining a high-emission status quo, and not to the easy answers and techno-fixes some would sell to farmers, but rather to other plans that credibly point the way to 30% or 50% reductions in emissions. There are plans that will suggest smaller costs and create smaller challenges, but those plans will also deliver much smaller results. Many will lead to higher, not lower, emissions in the future. Anyone who implies that there is a low-effort, low-cost route to cutting farm and food system emissions by 30% or 50% is naive or lying—probably both.

In crafting its plan, the NFU has taken account of the realities of farming. These include the vulnerable financial situation of farm families, the record-high farm debt levels that exist in nearly all Canadian provinces, the imbalance in market power between farmers and powerful agribusiness transnationals, the need to pursue sustainability in all its facets, the need to preserve farms and communities, the importance of clean water and healthy soils, and the limitations of government coffers. We have drawn a roadmap designed to protect farm families, ecosystems, and future generations. That said, it is simply not possible to create a plan that transforms agriculture yet leaves it unchanged, that replaces large parts of our machinery stock but incurs no costs, or that spurs rapid change but creates no uncertainty or dislocation. We have done the best we can to chart a course into the future. But our journey is not without risks and uncertainties. It is not without costs and sacrifices. Though one thing is certain: the costs of the proposed actions will be far lower than the cost of inaction or inadequate action—lower than the costs of climate chaos and scorched fields.

Conclusion

For the past 100 years, to feed the billions we have added to global populations, we have been pushing more and more energy into our food-production systems. These energy inputs have taken the form of machinery and fuels, pumped irrigation water, iron and steel, high-tech seeds from massively complex global technology firms, exotic petrochemicals, and, especially, energy-intensive fertilizers. The result is that we have created a food production system that is unprecedented in human history—one that is massively dependent upon fossil fuel sources and that emits billions of tonnes of climate-destabilizing greenhouse gases.

These emissions and the resulting climate destabilization are now disrupting our food-production efforts. Those disruptions will increase in frequency and severity as temperatures rise, storms intensify, floods and droughts occur more often, and ecosystems shift or collapse. As the 21st century progresses, our capacity to produce food will be challenged, and reduced.

To deal with our reduced capacities to produce food we will be encouraged by the dominant forces within the agri-food system to implement solutions: more irrigation, more fertilizer, increased dependence on high-tech seeds, etc. In short, to increase production we will be encouraged to do what we have done throughout the past century to increase production: push larger amounts of energy and inputs into our food systems in an attempt to push more food out. And as we do so, we will also push out more GHG emissions. Conventional thinking has locked us into a vicious circle: Energy use and attendant emissions endanger food production, and to maintain and increase food production we must inject more energy and risk more emissions. We have driven our food system down a civilizational cul-de-sac. We cannot go further. We must turn around. We have made a civilizational error. We need a new direction and a structural transformation.

For hundreds of thousands of years, there was no agriculture. Then, there was a civilizational transformation. Agriculture emerged. And for about a hundred centuries, there was agriculture that was solar powered, low-input, and net-zero emission. Then, a century ago, there was another civilizational transformation—to the fossil-fuelled agricultural and industrial systems we see around us today. We are now amid yet another civilizational transformation (forced upon us by the build-up of greenhouse gases in our atmosphere and our encounters with other planetary limits) away from fossil-fuelled systems, and toward wholly new ways of organizing and energizing human food, manufacturing, transportation, and economic systems. The thousands of farm family members that make up the NFU ask that governments stretch themselves to the very limits of their capacities and help marshal all the wisdom that can be accessed within this nation of Canada so that we may navigate this transformation and emerge from it healthier, happier, more secure, and in greater harmony with the Earth systems upon which all human life and commerce depend. This report is our initial contribution toward navigating this civilizational transformation.

Thank you
National Farmers Union
November 2019

Appendices

Appendix A. Farm income: Are things really so bad down on the farm?

This report argues that high on-farm emissions and low net farm incomes have the same cause: overdependence on purchased inputs. But some people, even some farmers, believe that farm incomes seem alright lately. Superficially this is true; in the decade since 2008 farm incomes seemed higher and more stable compared to the preceding 20 years. But is this really the case? Did the farm income crisis—a persistent problem since the latter-1980s—end in the latter-2000s? It is worth considering that it did not, even as we grant that the past decade has masked the worst effects of the crisis.

Table 11-1. Farm income, government payments, and debt, Canada, 2000-2018 (not adjusted for inflation)

*Figures not adjusted for inflation	**Canadian realized net farm income (billions of $ per year)**	**Government payments to farmers, net of premiums (billions of $ per yr)**	**Portion of realized net income derived from government payments (%)**	**Increase in farm debt (billions of $ per yr)**
2000	$2.14	$2.44	114%	$2.95
2001	$3.72	$3.43	92%	$1.83
2002	$3.07	$3.11	101%	$3.21
2003	$0.45	$4.26	947%	$3.00
2004	$2.37	$4.32	182%	$2.04
2005	$2.08	$4.51	217%	$1.37
2006	$1.05	$4.06	387%	$2.14
2007	$2.12	$3.31	156%	$3.55
2008	$3.75	$3.15	84%	$4.12
2009	$3.02	$2.37	78%	$2.77
2010	$3.56	$2.40	67%	$2.93
2011	$5.66	$2.52	45%	$2.63
2012	$6.51	$2.29	35%	$4.25
2013	$6.23	$1.55	25%	$5.20
2014	$7.16	$1.14	16%	$3.54
2015	$7.26	$1.29	18%	$4.86
2016	$7.31	$1.40	19%	$6.27
2017	$7.10	$1.60	23%	$5.60
2018	$3.90	$1.30	33%	$8.14
Total since 2000	**$78.46**	**$50.45**		**$70.39**
Total 2008-’18	**$61.46**	**$21.01**		**$50.29**
Average since 2000	**$4.13**	**$2.66**	**64%**	**$3.70**
Average 2008-’18	**$5.59**	**$1.91**	**34%**	**$4.57**

Sources: Statistics Canada Table 32-10-0052-01 (formerly CANSIM 002-0009); and Table 32-10-0051-01 (002-0008)

Table 11-1 shows Canadian farmers’ realized net income, government payments (net of premiums), and increases in debt levels. A few observations:

1. Net farm incomes since 2008 have been better (relative to previous low levels).
2. But even over the 2008-2018 period, fully one-third of net farm income has come from taxpayer-funded farm-support programs: Crop Insurance, AgriInvest, AgriStability, AgriRecovery.
3. In the 2008-2018 period, realized net farm income, with taxpayer-funded farm support payments factored out, averaged $3.68 billion per year (this figure is not shown in the table).
4. During that same period, however, farm debt rose by an average of $4.57 billion per year. This unrepaid money essentially served to “bulk up” cashflows and perceived net incomes.

5. Since 2008, on average, increased debt and government payments have added $6.48 billion per year to farmers' cashflows ($4.57 + $1.91 billion); realized net farm income from the market (i.e., with government payments netted out) averaged $3.68 billion per year. Is the crisis over?

In evaluating the post-2008 "better times" for farmers it is also worth considering the following ideas: First, as in the larger economy, income inequality is rising. In the post-2008 period some farmers have become rich—some capturing millions in net farm income. But most have struggled.

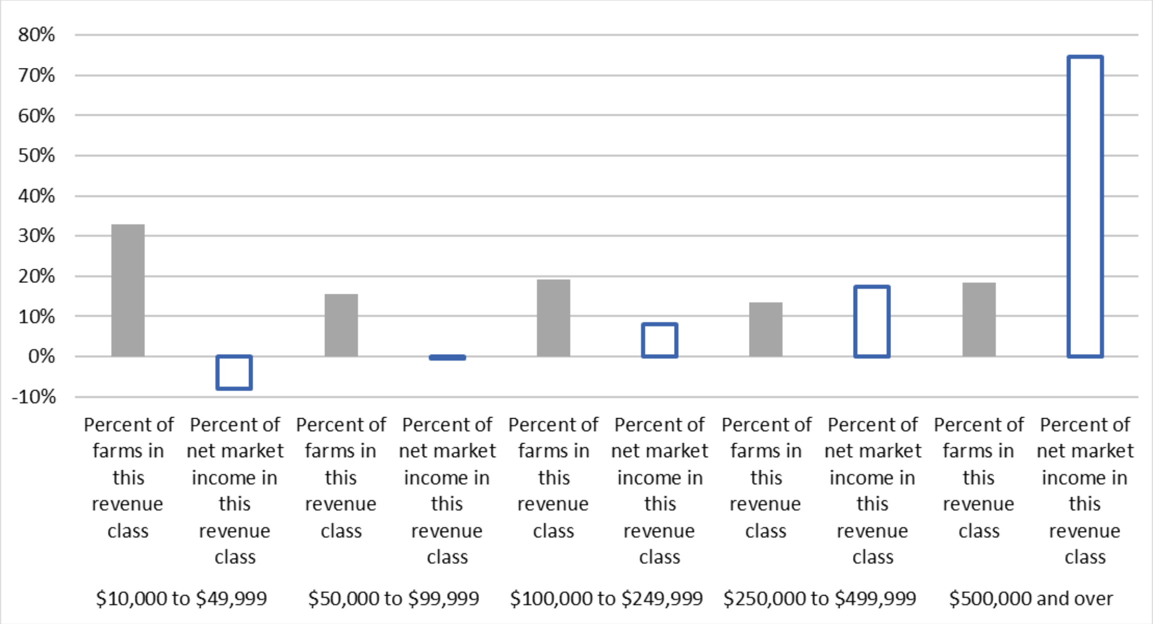

Figure 11-1. Net farm income shares, by revenue class, Canada, 2014
Source: Statistics Canada, CANSIM Table 002-0036

Figure 11-1 shows the percentage of farms in each of five revenue classes and the percentage of net income that flowed to those farms. The year is 2014, the most recent year for which this data is available. In the middle of the graph we see farmers with gross revenues of $100,000 to $249,999 per year. This income category includes about 20% of Canadian farms (see the middle grey bar), but those farmers shared less than 10% of net farm income (see the middle blue-outlined bar). On the right, we see farms with more than $500,000 per year in gross revenues. Farms in that revenue category made up just under 20% of Canadian farms. But that 20% captured about 75% of net farm income in 2014. And the remaining 80% of farms were left to share just 25% of net income. If a prosperous farm comes to mind, it is almost certainly part of the top 20%. But the situation on the other 80% of Canadian farms is far less rosy.

Second, some of those prosperous farms are obtaining their large incomes by farming land that used to support two or three families. Their net income is doubled because their land base has doubled. Many recent net income gains have come with corresponding losses in terms of farm numbers.

Third, increasing debt has had the effect of doubling farmers' cash flow again. Table 11-1 shows that every dollar of net income was augmented by another dollar of unrepaid debt.

Farming the neighbour's farm has effectively doubled net incomes and/or cash flows on some operations. Taking on more than $46 billion in unrepaid debt since 2008 has effectively doubled it again. And $21 billion in taxpayer-funded subsidies had increased it still further. Net farm income today is inadequate, inequitably distributed, enlarged by the cannibalization of neighbouring farms, subsidized by taxpayers, and floating atop a quantity of debt that it cannot repay. The production-maximizing, input-maximizing, emissions-maximizing model is a net-income loser—a farm destroyer.

Appendix B. Soil carbon sequestration

Eight things to keep in mind when thinking about soil carbon sequestration:

1. Soil carbon gains are hard to measure—requiring many, many measurements per field over several years. This is difficult and expensive.
2. Soil carbon levels eventually reach limits—soils become “saturated”: the rate at which carbon is added via plant mass and other sources reaches a new equilibrium with the rate at which soil microorganisms consume organic matter and release carbon as CO_2.
3. The amount of carbon that we can sequester into soils via enhanced management is roughly equal to the amount previously released by sub-optimum management. Degraded soils can absorb lots of carbon, but well-managed soils or soils that have never been farmed can absorb little. It is extremely hard to raise soil-carbon levels above those that existed at the time of European settlement. As noted above, in many parts of North America there is a “bison prairie maximum” to soil carbon levels.
4. Soil carbon sequestration quantities are often listed as rates: X kilograms or tonnes *per year*. The implication is that higher rates are better. But how fast carbon is stored into soils does not tell us *how much* carbon will be stored into those soils. Faster sequestration rates (tonnes per year) may simply lead to soils reaching equilibrium sooner.
5. Farming practices do not sequester carbon; certain positive *changes* in practices sequester carbon. For example, changing from poorly managed grazing (inappropriate stocking densities, etc.) to enhanced grazing management (perhaps rotational grazing) will sequester carbon in the soil. But if a piece of land has been grazed rotationally for many decades, it has likely stopped sequestering carbon. It is the change to a new, positive practice that has the effect.
6. Soil-sequestered carbon can be released. Just as a positive change in production practices can sequester soil carbon, a negative change can release it. Turning pasture or hayland into cropland, moving from reduced tillage to increased, or reinstating summer fallow (perhaps in response to problems with herbicide-resistant weeds) can rapidly de-sequester carbon. So can increased temperatures or decreased rainfall. When we burn fossil fuels we release carbon that was stably sequestered deep underground for millions of years. In contrast, when re re-sequester that carbon into soils, we put it into a place, just inches or feet below the ground, where it will be held much less securely and probably for just decades or centuries, not for millions of years.
7. Raising soil carbon levels in the form of soil organic matter requires not just carbon but also nitrogen. Carbon sequestration rates may be limited by nitrogen supplies. Stated another way, sometimes high carbon-sequestration rates are “fuelled” by adding supplementary nitrogen.
8. For the most part, sequestration is not counted. Carbon-counting frameworks at the UN and Canadian federal government level do not count carbon sequestration as an offset for emissions. There are, perhaps, good reasons for this stance. See “Appendix E. Net-net emissions accounting.” Raising soil carbon levels is very important—those levels are a key determinant of soil health and productivity—but our success or failure in that endeavour may not count toward meeting our emission-reduction commitments.

Appendix C. Nitrogen-oversaturated Earth

Nitrogen fertilizer production and use are the cause of nearly a third of all Canadian agricultural GHG emissions. But reasons to cut nitrogen use go far beyond emissions. The over-nitrification of the Earth is a growing problem. Globally, humans have tripled the amount of reactive (plant usable) nitrogen flowing into terrestrial ecosystems—into fields, forests, grasslands, and wetlands[76] This increased input comes primarily from farmers' application of fertilizer, but also from fossil-fuel combustion and cultivation of soybeans and other nitrogen-fixing crops. Though the global average increase is large and getting larger,[77] regional impacts are larger still. There are parts of North America, Asia, and Europe where nitrogen additions are ten times higher than natural rates.[78]

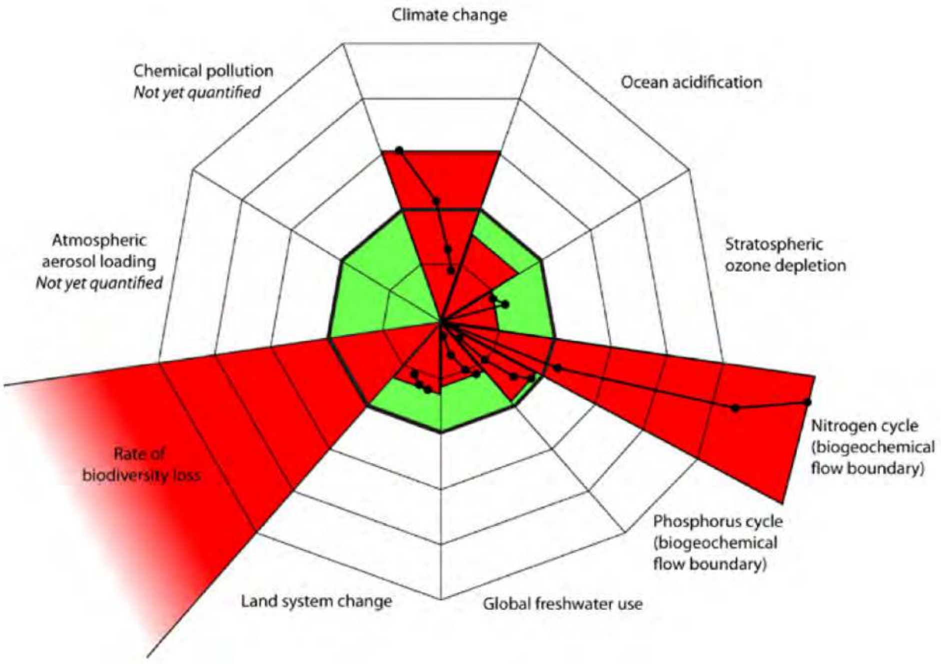

Figure 11-2. A diagram of human transgressions of planetary boundaries
Source: Copied from Johan Rocktrom et al., "Planetary Boundaries: Exploring the Safe Operating Space for Humanity," *Ecology and Society* 14, no. 2 (2009)

Nitrogen overload is now a top-tier threat to the biosphere. Will Steffen, Johan Rockstrom, and others have pioneered the concept of "planetary boundaries" and "the safe operating space for humanity." These scientists look at how far humans have pushed past safe limits in areas such as climate change, ozone depletion, and other areas. The consensus is that the two domains in which humans have pushed furthest past Earth's safe operating boundaries are biodiversity loss and our interventions in the nitrogen cycle.[79] See Figure 11-2. Hyper-nitrification of the biosphere is now a crisis. **No matter how we proceed regarding GHG emissions, nitrogen fertilizer use must be slashed.**

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[76] D. Fowler et al. "The Global Nitrogen Cycle in the Twenty-First Century," *Philosophical Transactions of the Royal Society* 368, no. 1621 (2013); A. Townsend and R. Howarth, "Fixing the Global Nitrogen Problem," *Scientific American*, Feb. 2010; J. Galloway et al., "Nitrogen Cycles: Past, Present, and Future," *Biogeochemistry* 70, no. 2 (2004); J. Galloway et al., "Transformations of the Nitrogen Cycle: Recent Trends, Questions, and Political Solutions," *Science* 320 (May 2008).

[77] J. Galloway et al., "Nitrogen Cycles: Past, Present, and Future," Biogeochemistry 70 (2004), Table 1; D. Tilman et al., "Forecasting Agriculturally Driven Global Environmental Change," *Science* 292 (April 2001).

[78] J. Galloway et al., "Transformations of the Nitrogen Cycle…" For a more explicit reiteration of Galloway's points see UNESCO and SCOPE, *Human Alteration of the Nitrogen Cycle: Threats, Benefits and Opportunities*, UNESCO and SCOPE Policy Brief No. 4, 2007, p. 4.

[79] Will Steffen et al., "Planetary Boundaries: Guiding Human Development on a Changing Planet," *Science* 347, no. 6223 (Feb. 2015), fig. 3. See also Johan Rockström et al., "Planetary Boundaries: Exploring the Safe Operating Space for Humanity," *Ecology and Society* 14, no. 2 (Dec. 2009), Article 32.

Appendix D. Organic agriculture: energy efficiency and emissions

Most studies find that organic grain, livestock, and mixed-farm production systems use less energy and produce fewer emissions per acre and per tonne of output. Further, organic production systems and products usually better protect water quality and biodiversity and can have human-health benefits. Finally, organic systems increase farmers' net returns per acre and per tonne. This Appendix introduces some of the research on energy use in, and emissions from, organic agriculture.

A 2006 peer-reviewed journal article coauthored by Jeff Hoeppner, Martin Entz, Brian McConkey, Robert Zentner, and Cecil Nagy detailed the results of a 12-year study at Glenlea, Manitoba.[80] The study compared organic and conventional crop-production systems and calculated energy inputs, outputs (crop or forage tonnage), and energy efficiency. Two four-year rotations were studied: wheat-pea-wheat-flax (the "grain-based rotation") and wheat-alfalfa-alfalfa-flax (the "integrated rotation"). Conventional and organic systems were run side-by-side, and each four-year rotation was run through three complete cycles over a 12-year period, 1992–2003. The study found that: "the conventional system in the integrated rotation [wheat-alfalfa-alfalfa-flax] consumed 2.2 times the non-renewable energy as the organic system, while the conventional system in the grain-based rotation [wheat-pea-wheat-flax] consumed 2.8 times the energy as the organic system. Fertilizer contributed most to the difference in energy input between conventional and organic systems, accounting for 51 and 43% of the total energy input of the conventional systems in the grain-based and integrated forage–grain rotations, respectively."

While energy inputs were higher for the conventional system, energy *outputs*—grain and forage yields—were also higher, by approximately 40%. Despite this, and because of the organic system's much lower energy inputs, that production system had a 40% higher energy efficiency, as defined by the ratio between energy inputs and outputs. (No manure was applied to the organic system.) For a given energy input, the organic production system produced 40% more food and forage.[81] The study concluded that "energy efficiency increased as energy inputs were reduced" and that "the organic system outperformed the conventional system on the basis of lower energy inputs and higher energy efficiency." One important consideration, however, is that the conventional agricultural system compared in the study was not a no-till system. Both the organic and conventional systems utilized spring and fall tillage. So then, while the study provides strong, Prairie-relevant evidence that within tillage-based systems organic agriculture is more energy efficient, the article does not answer the question of whether organic production is more energy efficient than conventional *no-till* production.

A 2000 article in the prestigious journal *Science* by Robertson et al. does address the question of comparative emissions of organic relative to no-till crop production. The paper summarized a 9-year study (1991-1999) in Michigan, in the northern part of the US corn belt. The study looked at four corn-wheat-soybean rotations and compared the emissions of several systems, including conventional no-till and organic. Robertson et al. found that GHG emissions from no-till conventional systems were 1.24 tonnes CO_2e per hectare; and from organic 0.70 tonnes CO_2e per hectare—44% less (soil carbon sequestration excluded).[82] This is on a per-area basis: per hectare. It is likely that organic production would also have lower emissions per tonne of grain produced, because its yields are not, on average, 44% less than

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[80] J. Hoeppner et al., "Energy Use and Efficiency in Two Canadian Organic and Conventional Crop Production Systems," *Renewable Agriculture and Food Systems* 21, no. 01 (March 2006).

[81] The authors raised one caveat: soil phosphorous levels declined in the organic system and the energy cost of replacing that phosphorus was not fully accounted for. But such energy costs, if fully counted, would not significantly alter the energy efficiency advantage of the organic system.

[82] G. Robertson, E. Paul, and R. Harwood. "Greenhouse Gases in Intensive Agriculture: Contributions of Individual Gases to the Radiative Forcing of the Atmosphere." *Science* 289, no. 5486 (September 15, 2000), Table 2.

conventional no-till yields. Robertson et al. call fossil-fuel derived fertilizers, fuels, lime, and chemicals "CO_2-producing crop subsidies."

Many studies provide evidence that organic and low-input agriculture have superior energy efficiency compared to high-input no-till systems, and lower emissions per hectare or per tonne. A 2011 journal article by Kulshreshtha and Klemmer[83] modelled a transition of 10% of Canadian farmland to organic production and found that after conversion, GHG emissions per acre would be 45% lower, and, on a per-tonne basis, more than 25 % lower. Net farm income, employment, and GDP would all rise.

A 2008 journal article by Pelletier, Arsenault, and Tyedmers modelled a hypothetical transition of 100% of Canada's four major crops—canola, corn, soybeans, and wheat—to organic production. That study concluded that: "[O]rganic crop production would consume, on average, 39% as much energy and generate 77% of the global warming emissions, 17% of the ozone-depleting emissions, and 96% of the acidifying emissions associated with current national production of these crops. These differences were almost exclusively due to the differences in fertilizers used in conventional and organic farming and were most strongly influenced by the higher cumulative energy demand and emissions associated with producing conventional nitrogen fertilizers compared to the green manure production used for biological nitrogen fixation in organic agriculture."[84] On a per-tonne basis, the greenhouse gas emission advantage for organic production would hold unless one assumes overall organic yields are less than 77% of conventional yields—an assumption few studies would support.

Not all studies supported the conclusion that organic farming systems produce lower emissions per tonne of production. For example, Hanna Tuomisto and her coauthors synthesized data from 71 studies looking at European agriculture and found that although organic farmers produce less GHG per unit of area (acre or hectare) the studies show that organic farms emit more GHGs per unit of production (per tonne or bushel).[85]

Table 11-2 lists and summarizes some of the many relevant studies.

Table 11-2. Studies of energy use in organic production systems

Study	Type	Locations	Based on:	Energy efficiency gains	GHG reductions
Lee et al., 2015, "Measuring the Environmental Effects of Organic Farming: A Meta-Analysis of Structural Variables in Empirical Research"[86]	Review/ meta-analysis	Global	107 studies and 360 observations published between 1977 and 2012	In studies that calculated energy efficiency (EE), "67.3% of the 165 observations exhibited positive outcomes…. That is, in terms of EE, organic farming was favored over conventional farming." The meta-analysis lumped together energy use per area (hectare) with energy use per unit of output (tonne or Gj) making results hard to interpret.	"Of the 195 observations, 67.7% exhibited positive outcomes …. That is, in terms of GHGE, organic farming was favored over conventional farming." These results are ambiguous, however, because the meta-analysis lumped together GHG per area (per hectare) with GHG per unit of output (per tonne or per Gj).

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[83] S. Kulshreshtha and C. Klemmer, "Environmental and Economic Evaluation of Conventional and Organic Production Systems in the Canadian Prairie Provinces," in *Food and Environment: The Quest for a Sustainable Future*, ed. V. Popov, and C. Brebbia, (Ashurst, UK: WIT Press, 2011).

[84] N. Pelletier, N. Arsenault, and P. Tyedmers, "Scenario Modeling Potential Eco-Efficiency Gains from a Transition to Organic Agriculture: Life Cycle Perspectives on Canadian Canola, Corn, Soy, and Wheat Production," *Environmental Management* 42, no. 6 (2008).

[85] H. Tuomisto et al., "Does Organic Farming Reduce Environmental Impacts? – A Meta-Analysis of European Research," *Journal of Environmental Management* 112 (December 15, 2012).

[86] Ki Song Lee, Young Chan Choe, and Sung Hee Park, "Measuring the Environmental Effects of Organic Farming: A Meta-Analysis of Structural Variables in Empirical Research," *Journal of Environmental Management* 162 (October 1, 2015).

Study	Type	Locations	Based on:	Energy efficiency gains	GHG reductions
Smith et al., 2013, "The Energy Efficiency of Organic Agriculture: A Review"[87]	Review		50 studies of various crop, livestock, and horticultural systems.	"Energy use for cereal cropping is approximately 80% of conventional per unit of product...." "...for most grazing systems, organic farming will result in lower energy use, on a unit area or weight of product basis." "Overall it would appear that the energy efficiency of most cropping and ruminant livestock systems can be enhanced through the adoption of organic management."	n.a.
Cooper et al., 2011, "Life Cycle Analysis of Greenhouse Gas Emissions from Organic and Conventional Food Production Systems, with and without Bio-Energy Options"[88]	Field trials	UK	Four years of data (2004-2007) from the Nafferton Factorial Systems Comparison (NFSC) and various organic and conventional rotations and mixes of livestock and crops.		Contains data on food production (Gj) per hectare and emissions per ha (tonnes CO_2e). Thus, one can calc. Gj of food prod. per tonne of emissions. In systems without livestock organic systems produced twice as much food per tonne of emissions. In systems with livestock, organic systems produced 1.5 times more food per tonne of emissions.
Kulshreshtha and Klemmer, 2011, "Environmental and Economic Evaluation of Conventional and Organic Production Systems in the Canadian Prairie Provinces"[89]	Model	Canada (Prairies)	Three models are integrated to simulate the conversion of 10% of Prairie cropland to organic production	n/a	After conversion, GHG emissions per acre would fall 45%. Emissions per tonne would be more than 25% lower. Net farm income, employment, and GDP would rise.
R. Zentner et al., 2011, "Effects of Input Management and Crop Diversity on Non-Renewable Energy Use Efficiency of Cropping Systems in the Canadian Prairie"[90]	Field trials	Scott, SK (AAFC research stn.)	12 years of data (1996-2007) on 9 systems and 3 levels of inputs (high, reduced, & organic) and 3 rotations.	Despite the fact that yields from the organic systems were unusually low (63% of output from the high input systems) the energy use efficiency of the organic system was still the highest: 22-27% higher	n.a.
Pelletier et al., 2008, "Scenario Modeling Potential Eco-Efficiency Gains from a Transition to Organic Agriculture"[91]	Cradle-to-farm-gate Life Cycle Analysis (LCA) model	Canada	A hypothetical national transition to organic production focused on Canada's major crops: canola, corn, soybeans, and wheat.	"Our results indicate that organic crop production would consume, on average, 39% as much energy and generate ... 17% of the ozone-depleting emissions, and 96% of the acidifying emissions associated with current national production of these crops. These differences were almost exclusively due to the differences in fertilizers used in conventional and organic farming."	"... organic crop production would ... generate 77% of the global warming emissions associated with current national production of these crops." This is on a per-area basis. This advantage would persist but be lower on a per-output basis.

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[87] L. Smith, A. Williams, and B. Pearce, "The Energy Efficiency of Organic Agriculture: A Review," *Renewable Agriculture and Food Systems* 30, no. 03 (June 2015).

[88] J. Cooper, G. Butler, and C. Leifert, "Life Cycle Analysis of Greenhouse Gas Emissions from Organic and Conventional Food Production Systems, with and without Bio-Energy Options," *NJAS - Wageningen Journal of Life Sciences* 58, no. 3–4 (December 2011).

[89] S. Kulshreshtha and C. Klemmer, "Environmental and Economic Evaluation of Conventional and Organic Production Systems in the Canadian Prairie Provinces," in *Food and Environment: The Quest for a Sustainable Future*, ed. V. Popov, and C. Brebbia, (Ashurst, UK: WIT Press, 2011).

[90] R. Zentner et al., "Effects of Input Management and Crop Diversity on Non-Renewable Energy Use Efficiency of Cropping Systems in the Canadian Prairie," *European Journal of Agronomy* 34 (2011)

[91] N. Pelletier, N. Arsenault, and P. Tyedmers, "Scenario Modeling Potential Eco-Efficiency Gains from a Transition to Organic Agriculture," *Environmental Management* 42 (2008).

Study	Type	Locations	Based on:	Energy efficiency gains	GHG reductions
Gomiero et al. 2008, "Energy and Environmental Issues in Organic and Conventional Agriculture"[92]	Review	EU, USA, and Canada	Several studies of various crop, livestock, and horticultural system.	"The data indicates, for most cases, lower energy consumption for organic farming both for unit of land (Gj/ha), from 10% up to 70%, and per yield (Gj/t), from 15% to 45%." "Organic agriculture performs much better than conventional concerning energy efficiency...."	Results were unclear and emissions per tonne not calculated. The report concludes, however, that "organic agriculture represents an interesting option to reduce energy consumption, CO_2 and other GHG emissions, as well as to preserve soil health and biodiversity."
Hoeppner et al., 2006, "Energy Use and Efficiency in Two Canadian Organic and Conventional Crop Production Systems"[93]	Field trials	Manitoba (Glenlea)	Two rotations: wheat-pea-wheat-flax and wheat-alfalfa-alfalfa-flax. Three 4-year rotation cycles.	"...energy efficiency was 40% higher for organic compared with the conventional system."	n/a
Khakbazan et al., 2004, "Evaluating Economics of Greenhouse Gas Emission Under High and Low Input Farming System"[94]	Field trials	Manitoba	Not a study of organics, per se, but of low- vs. high-input systems (various rates of fertilizer and pesticide use). Wheat-pea rotation and 2 replications of the rotation in four years: 1998-2001.	"Energy output/input ratios [i.e., energy efficiency] were highest for 25% fertilizer rate and lowest for 100% fertilizer rate...." The report also found that using 25% of the recommended fertilizer rate also produce the highest net incomes—several times higher than those earned when applying 100% of the recommended rate.	The study looked at GHG emissions but did not report them clearly, or in terms of GHG emissions per unit of output. (They instead reported emissions per hectare.)
Robertson et al., 2000, "Greenhouse Gases in Intensive Agriculture"[95]	Field trials	US (Midwest)	Four corn-wheat-soybean rotations over 9 years, 1991-1999.	n/a	Conventional no-till systems have lower net emissions in the short term (2-4 decades) because of larger carbon sequestration effects. Longer term, organic systems have the lowest emissions (once soils reach carbon saturation). This study supports organic production as a measure to reduce GHG emissions.
Tuomisto, 2012, "Does Organic Farming Reduce Environmental Impacts? – A Meta-Analysis of European Research"[96]	Modelling, LCA, and secondary data analysis.	The UK was the basis for the model.	5 production systems including organic, conventional, and "integrated" (combining the best aspects of organic and conventional)		

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[92] T. Gomiero, M. Paoletti, and D. Pimentel, "Energy and Environmental Issues in Organic and Conventional Agriculture," *Critical Reviews in Plant Sciences* 27, no. 4 (August 5, 2008).

[93] J. Hoeppner et al., "Energy Use and Efficiency in Two Canadian Organic and Conventional Crop Production Systems," *Renewable Agriculture and Food Systems* 21, no. 1 (March 2006).

[94] M. Khakbazan et al., "Evaluating Economics of Greenhouse Gas Emission Under High and Low Input Farming System," in *Canadian Agricultural Economics Society*, 2004.

[95] Robertson, Paul, and Harwood, "Greenhouse Gases in Intensive Agriculture."

[96] Tuomisto et al., "Does Organic Farming Reduce Environmental Impacts?"

Study	Type	Locations	Based on:	Energy efficiency gains	GHG reductions
Tuomisto et al., 2012, "Comparing Energy Balances, Greenhouse Gas Balances and Biodiversity Impacts of Contrasting Farming Systems with Alternative Land Uses"[97]					
Teasdale et al. 2007[98]	Field trial	US (Maryland)	9 years of field trials and 3 years of follow-up fertility testing. 4 systems compared.	No energy efficiency data was reported, but the article does report yield and other data and many other important insights.	n.a.
Nonhebel, 2002[99]					
Lynch et al., 2011[100]					
Lynch, 2009[101]					
Stockdale et al. 2001[102]					
Stolze et al., 2000[103]					
Erisman et al., 2008[104]					
Azeez and Hewlett[105]					
Clancy et al., 1993[106]					
Wortman et al. 2011[107]					
Niggli et al., 2009[108]					
Meisterling et al., 2009[109]					
Cavigelli et al., 2009[110]					

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[97] H. Tuomisto et al., "Comparing Energy Balances, Greenhouse Gas Balances and Biodiversity Impacts of Contrasting Farming Systems with Alternative Land Uses," *Agricultural Systems* 108 (April 2012).

[98] J. Teasdale, C. Coffman, and R. Mangum. "Potential Long-Term Benefits of No-Tillage and Organic Cropping Systems for Grain Production and Soil Improvement." *Agronomy Journal* 99, no. 5 (2007).

[99] S. Nonhebel, "Energy Use Efficiency in Biomass Production Systems," in *Economics of Sustainable Energy in Agriculture*, ed. E. van Ierland and Alfons Oude Lansink, (Springer Netherlands, 2002).

[100] D. Lynch, R. MacRae, and R. Martin, "The Carbon and Global Warming Potential Impacts of Organic Farming: Does It Have a Significant Role in an Energy Constrained World?," *Sustainability* 3, no. 12 (January 28, 2011).

[101] D. Lynch, "Environmental Impacts of Organic Agriculture: A Canadian Perspective," *Canadian Journal of Plant Science* 89, no. 4 (July 1, 2009).

[102] E. Stockdale et al., "Agronomic and Environmental Implications of Organic Farming Systems," *Advances in Agronomy* 70.

[103] M. Stolze et al., *Environmental impacts of organic farming in Europe* (Universität Hohenheim, Stuttgart-Hohenheim, 2000).

[104] J. Erisman et al., "How a Century of Ammonia Synthesis Changed the World," *Nature Geoscience* 1, no. 10 (October 2008).

[105] G. Azeez and K. Hewlett, "The Comparative Energy Efficiency of Organic Farming," presentation, 16th IFOAM Organic World Congress, Modena, Italy, June 16-20, 2008

[106] S. Clancy et al., *Farming Practices for a Sustainable Agriculture in North Dakota* (North Dakota State University, Carrington Research Center, 1993).

[107] S. Wortman et al., "Soil Fertility and Crop Yields in Long-Term Organic and Conventional Cropping Systems in Eastern Nebraska," *Renewable Agriculture and Food Systems* 27, no. 3 (2011).

[108] U. Niggli et al., "Low Greenhouse Gas Agriculture: Mitigation and Adaptation Potential of Sustainable Farming Systems" (Rome: UN FAO, 2009).

[109] K. Meisterling, C. Samaras, and V. Schweizer, "Decisions to Reduce Greenhouse Gases from Agriculture and Product Transport: LCA Case Study of Organic and Conventional Wheat," *Journal of Cleaner Production* 17, no. 2 (2009).

[110] M. Cavigelli et al., "Global Warming Potential of Organic and Conventional Grain Cropping Systems in the Mid-Atlantic Region of the US," in *Proceedings of the Farming System Design Conference*, 25 (2009).

Appendix E. Net-net emissions accounting

In calculating national emission levels and evaluating Canada's success in reaching its Paris targets the UN and other emission-accounting bodies will not count overall soil carbon sequestration; they will only count *increases* in the rate of sequestration *over and above* the relatively high levels that existed in 2005, the reference year for our Paris commitments and 2030 targets. For the most part, sequestration won't count. Worse, it may count against us if sequestration rates are below 2005 levels (which is likely).

In the lead-up to the 2015 Paris climate conference, Canada committed to "to achieve an economy-wide target to reduce our greenhouse gas emissions by 30% below 2005 levels by 2030." The official document outlining Canada's target—our "intended nationally determined contribution" (INDC)—is just four pages long. In regard to accounting for agriculture, forestry, and other land uses, it says: "Canada intends to account for the land sector using a net-net approach…." What is a net-net approach? In this approach, it is the *change* in the carbon flux that is measured—the net difference in the flux in 2030 compared to 2005. "Only the difference between the emissions and removals [i.e., sequestration] that occur … each year of the commitment period and the emissions and removals that occurred … during the base year … are accounted for. *This accounting rule tries to capture the emissions and removals that are 'additional' to those observed in the base year*" [italics added].[111] Thus, soil carbon sequestration will count toward meeting our 2030 commitment in proportion to how much *larger* those 2030 sequestration rates are compared to sequestration rates in the base year, 2005.

This creates perverse scenarios. Recall that over time soils approach carbon saturation, and that continuing to do the right thing—zero-tilling, employing better crop rotations, etc.—yields lower rates of sequestration. This can happen even if farmers work as hard as they can to sequester carbon, doing everything right on every acre and applying every BMP. In 2030 farmers may be working harder and smarter to sequester soil carbon, but those sequestration rates will probably be lower than in 2005. If this is the case—if overall sequestered tonnage continues to accumulate but *rates* of *annual* sequestration *fall*—then the soil carbon sequestration category will count as a *negative* (as if we emitted more) when emissions are tallied. Farmers and policymakers should not count on soil carbon sequestration to allow them to avoid hard choices regarding agricultural GHG emissions. Based on the preceding, we can make three observations about soil carbon sequestration vis a vis meeting our emissions targets:

1. The potential for soil carbon sequestration to contribute to meeting our emission-reduction targets (i.e., the potential for future rates to be significantly larger than 2005 rates) is low.

2. Future rates of soil sequestration are unknown: soil saturation timelines are disputed; farmers may have to revert to tillage to control herbicide-resistant weeds; and hot, dry weather may slow or reverse sequestration.

3. Net-net accounting can be seen as unfair to farmers. Eventually, soil carbon saturation will reduce sequestration rates to near-zero. As rates fall, *this decline in removals will be counted identically to increases in emissions*. This may partly negate farmers' emission-reduction successes. Farmers will be penalized for failing to do the impossible: to push carbon into soils ever faster even as soils fill up and accept carbon ever more slowly.

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[111] Paulo Canaveira, "Options and Elements for an Accounting Framework for the Land Sector in the Post-2020 Climate Regime," Terraprima Report to the Swiss Federal Office for the Environment, 2014.

Appendix F. Precision farming and agricultural Big Data

An analysis of precision farming technologies reveals why it is critical to evaluate emission-reduction technologies in their political, economic, and social *contexts*. Precision farming technologies can provide significant emissions reductions. It is likely, however, that these and related technologies will also have negative effects on farmers' incomes, autonomy, market power, and even on the capacity of smaller operations to continue producing.

Precision farming hardware and software can increase yields and input-use efficiency, and decrease input use, costs, and GHG emissions. Experts' reports and science journal articles claim that precision farming techniques can reduce crop-production emissions by several percent, mostly as a result of variable-rate nitrogen application and the reduced use of, and emissions from, those fertilizers, and from reducing overlap and double-application by utilizing section-control systems.

The problem is that these technologies come attached to another suite of technologies: agricultural Big Data. We can grasp the difference between the two sets of technologies this way: In precision farming, a farmer could collect data and use that information to control his or her machinery to increase input-use efficiency or yields. The data could stay on his or her farm, wholly under his or her control. In contrast, Big Data brings other powerful players into the mix. In such systems, a farmer's data would often be collected by a networked "technology platform" with data links, not only to the technology provider or machinery company that made the hardware or software, but also to the dominant seed, chemical, and fertilizer corporations. In agricultural Big Data systems, the farmers' information is often housed, not on his or her farm, but in the cloud, on servers controlled by input or machinery companies. The data is sometimes aggregated and used to create predictive input-use algorithms. And the data—either from individual farms or in aggregated form—can be licenced or sold to third parties. There is great potential for farmers' data to be used in ways that hurt farmers. Some worry that data on yield or input use could be employed to police farmers' use of patented seeds, identify high-yielding land for speculative buy-up, even to gain an advantage in futures markets. Just as Google and similar companies collect and sell information about our online activities, farmers are concerned that precision-farming platforms may become data-harvesting pathways for agribusiness—providing seeded-acreage or crop-yield data to Cargill, fertilizer-use data to Nutrien, and seed- and chemical-use information to Bayer-Monsanto. Big Data smacks of Big Brother. Farmers may soon have to wonder whether their combines or sprayers are spying on them. To realize how inappropriate such a situation is, imagine the tables turned: How would Deere, Bayer, or Cargill respond if farmers wanted to install millions of sensors within these corporations to collect data to be housed on farmer-controlled servers?

Agricultural Big Data is not just precision farming with cloud-computing convenience. No, precision farming and Big Data seek to accomplish very different aims. Precision farming technologies provide ways for farmers to control machinery; Big Data systems provide ways for corporations to control farmers—to alter their seed-buying, fertilizer application, and chemical choices. With the advent of Big Data, precision farming hardware components—GPS receivers, variable rate attachments for air carts, yield monitors, etc.—are no longer the actual products. Rather, they become means to an end—delivery systems for "planting prescriptions" from Bayer-Monsanto and other companies: seed, chemical, and fertilizer prescriptions the dominant input corporations prepare and that farmers apply. The plan seems to be that farmers will buy the precision farming hardware, then farmers will buy the Big Data agro-prescriptions that show farmers the proper mix and rates of inputs, and then farmers will buy the actual input packages. The potential for profit-transfer and eroded farmer autonomy are obvious. (See sidebar on "Corporate agro-prescriptions")

But the situation may become even worse. Machinery, fertilizer, chemical, seed, and precision-farming-technology companies may soon begin merging across sectoral lines to create amalgamated machinery-fertilizer-seed/genetics-chemical-information behemoths. When this happens, no one should be surprised. Agricultural chemicals and seeds used to be separate sectors. Today they are one. Companies such as Bayer-Monsanto, ChemChina-Syngenta, and Dow-DuPont are now integrated seed-chemical companies. An astute observer would now be watching to see, not only which companies are about to merge, but which *sectors* are about to be merged. Machinery companies may soon begin purchasing seed-chemical companies, or seed-chemical companies may begin purchasing fertilizer companies, or vice-versa. Mergers within *and between* sectors are part of the agribusiness landscape. Precision farming/Big Data provides the unifying, cross-cutting technologies—the business case for the creation of global mach-fert-seed-chem-info corps. The effects on family farmers would be devastating. This is another reason to work to reduce farmers' dependence on purchased inputs.

There is yet another factor: Precision farming technologies are not scale neutral. These systems—costly both in terms of money and managerial time—are best suited to large farms that can afford newer equipment, spread costs over thousands of acres, and assign an employee or family member the task of managing the Big Data information systems, hardware, data, and agro-prescriptions. The proliferation of costly precision farming technologies may disadvantage smaller farms, raise the size of a "viable" operation, and speed the expulsion of farmers. Canada has lost *half* its farmers in just two generations. Precision farming systems that come wrapped in Big Data packages and that tie farmers to merged machinery-fertilizer-seed-chemical-information behemoths will only speed the expulsion of farmers. Technologies that reduce emissions *and* reduce farmers' autonomy *and* potentially reduce farm numbers are technologies that all must reject.

Finally, there is a probability that precision farming technologies, touted as profit-enhancing *options*, will be turned into costly *necessities* as every farmer is forced to purchase the hardware and services in order to remain competitive, or to comply with emission-reduction dictates.

Agricultural Big Data create so many problems that it is impossible to offer a complete solution. Moreover, it is beyond the scope of this report—focused on emission-reduction strategies—to formulate complete solutions to the corporate-power issues raised by Big Data and corporate mergers. Nonetheless, some initial suggestions to government could include:

1. Governments must regulate the precision farming and Big Data sectors to ensure the confidentiality of farmers' agronomic, yield, and input-use data. To this end, governments must ensure that farmers can utilize precision farming technologies and information services without transferring data to third parties. *All the services and "solutions" currently on offer can be made available to farmers in ways that allow farmers to retain their data on their own computers or on secure servers of their choice and not transfer that data to agribusiness corporations or third parties.*

2. Governments must ensure that there is sufficient competition in the input sectors. To this end, governments must halt mergers within and between sectors.

3. Governments must counter the "market forces" pushing our society toward larger farms and fewer farmers. The uncertain and often-destructive weather that will result from climate change means that we must maximize our ability to adapt quickly. We will want to increase the number of farmers on the landscape and the diversity within our farming systems.

Until these and other changes are made, governments should not endorse or promote precision farming technologies, taxpayers should not subsidize them, and farmers should not adopt them.

This report has devoted significant attention to precision farming and Big Data because these technologies raise significant issues, but also *to demonstrate how the assessment of all emission-reduction technologies should be approached*. Technologies often come with hidden costs, strings attached, unintended consequences, and corporate power- or profit-grabs. In formulating a plan to cut agricultural emissions by half—that is to say, in formulating a plan to transform Canadian agriculture—we must look beyond GHG tonnage. We must evaluate how new technologies, on-farm measures, and government policies contribute to our *multiple* goals of stable and prosperous farms, beautiful and populated rural areas, safe and nutritious food, and a healthy environment.

Corporate agro-prescriptions

University of Missouri economist Dr. Michael Sykuta describes one example of seed and chemical company prescriptions:

Monsanto's FieldScripts® program requires two years of raw yield data in addition to soil and field mapping data to generate its planting prescriptions. The farmer also provides information on anticipated planting dates, yield goals, row spacing, and variable-rate planting ranges. Once the data are sent from the local certified dealer to Monsanto, a primary and secondary planting recommendation is developed offering two DEKALB® seed types and planting densities. [DEKALB is a Monsanto company.] A preview of the prescription is reviewed with the local dealer, at which point the farmer can choose whether to purchase the prescription, which is priced on a per acre basis ($5/acre in 2015). The farmer can then download the prescribed planting instructions for the hybrid of choice to an iPad app which will then guide the variable-rate planting equipment to plant accordingly.

Although the farmer does not have to pay until after a preview of the prescriptions is available, the farmer's data are already passed to Monsanto…. Furthermore, only Monsanto's DEKALB® seed hybrids are available using the FieldScripts® program. When the farmer accepts the prescription, she agrees to purchase prescribed seed variety at the same time, before the planting program is downloaded to the farmer's iPad.

—From Michael Sykuta, "Big Data in Agriculture: Property Rights, Privacy and Competition in Ag Data Services." *International Food and Agribusiness Management Review* 19 (2016).

Appendix G. Livestock numbers

There are a lot of cattle on the planet—1.5 billion head. In addition, there are 3 billion sheep, goats, and hogs, and tens-of-billions of chickens, turkeys, and ducks.[112] We humans and our livestock have come to dominate the planet. Figure 11-3 shows the mass of humans, our domesticated livestock, and wild animals (terrestrial mammals and birds). The units, though unimportant, are millions of tonnes of carbon. Three periods are shown. The first is 50,000 years ago: the time before the Quaternary megafauna extinction (when *Homo sapiens* radiated outward into Eurasia and contributed to the extinction of about half the planet's large animal species). In the middle of the graph is the period around 11,000 years ago—before humans began practicing agriculture. On the right is the situation today. Not surprising, the first two periods are dominated by wild animals; the mass of humans in those periods is so small that the blue bar representing our biomass is not even visible.

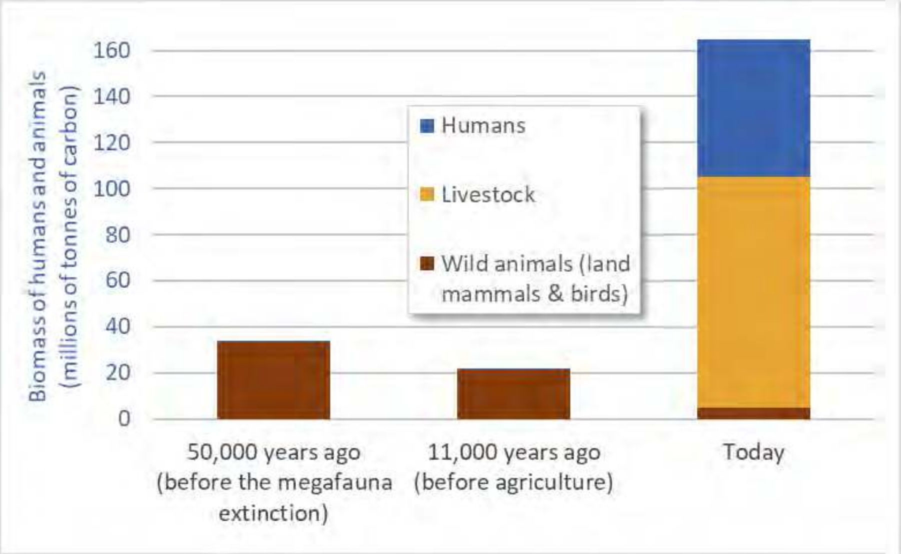

Figure 11-3. Mass of humans, livestock, and wild animals (terrestrial mammals and birds)
Sources: Yinon M. Bar-On, Rob Phillips, and Ron Milo, "The Biomass Distribution on Earth," *Proceedings of the National Academy of Sciences* 115 (June 2018); Anthony Barnosky, "Megafauna Biomass Tradeoff as a Driver of Quaternary and Future Extinctions," *Proceedings of the National Academy of Sciences* 105 (August 2008); Vaclav Smil, *Harvesting the Biosphere: What We Have Taken from Nature* (Cambridge, MA: MIT Press, 2013)

But note the situation today. Humans and our domesticated animals now dominate the Earth. The mass of humans and domesticates is approximately 32 times the mass of wild animals and birds. Humans and our livestock now make up 97% of all animals on land. Wild mammals and birds have been reduced to a remnant: just 3%. This is the main reason why the Earth is undergoing most rapid extinction event in 65 million years.[113] While there may be a question as to whether there are too many livestock animals in Canada, it seems clear that there are too many on Earth. Even more problematic, global meat production has doubled since 1986, quadrupled since 1964,[114] and remains on track to double again this century.[115]

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[112] United Nations Food and Agriculture Organization (UN FAO), FAOSTAT website, "Production: Live animals," http://faostat3.fao.org/browse/Q/QA/E Accessed September 29, 2016.

[113] *Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Synthesis, 2005*, (Island Press, Washington, DC.), 5, 36, & 38.

[114] FAOSTAT website, "Production: Livestock primary,"

[115] Nikos Alexandratos, Jelle Bruinsma, and others, "World Agriculture Towards 2030/2050: The 2012 Revision," EAS Working Paper (Rome: UN FAO, 2012), http://large.stanford.edu/courses/2014/ph240/yuan2/docs/ap106e.pdf.

Appendix H. The emissions balance of cattle: CH_4 emissions vs CO_2 sequestration

Those who advocate for cattle sometimes make the case that they can be a climate solution—that good grazing management can cause more GHG tonnes to be sequestered in soils than are emitted by cattle. In preparing this report, much research was done on this question. The arguments and counterarguments are complicated and the evidence appears fragmentary, incomplete, and inconclusive. Even the experts are uncertain regarding the relative size of emissions and sequestration. A 2010 report in the *Journal of Environmental Quality* highlights that “clear determination of grassland ecosystems as net sinks or sources of greenhouse gases (GHGs) is limited by a paucity of information regarding management impacts on the flux of … methane….”[116]

This report takes an agnostic position on the question of whether a significant part of our cattle-production system can be made GHG-neutral or -negative—whether, on any broad scale, grasslands can be made to sequester more GHGs than cattle emit, and whether such a happy state of affairs can be continued for any significant length of time or propagated broadly. Most important, this report takes the position that this is the wrong standard. Grassland herbivores tend to be net GHG emitters and other organisms in the ecosystems and processes in the atmosphere consume or destroy that methane and balance atmospheric concentrations. ***It has never been a feature of natural, sustainable ecosystems that herbivore-grassland ecosystems must remove more GHGs than they emit.*** That said, the following collects some of the data about relative emissions and sequestration rates.

Estimates of cattle methane emissions

Table 11-3 provides some baseline data about emissions per animal. Table 11-4 shows two estimates of total GHG emissions per kg of beef produced.

Table 11-3: Cattle: emissions per animal, kgs of CO_2e per head per year

	Estimates used by Kulshreshthra et al., 2016[117]			**IPCC Tier 1 methodology**[118]		**IPCC Tier 2 methodology**[119]		**Estimates based on Canadian studies**[120]	
	Methane emissions (kgs of CH_4 per head per year)	Factor to convert kgs CH_4 to kgs CO_2e	**Methane emissions (kgs CO_2e per head per year)**	Methane emissions (kgs of CH_4 per head per year)	**Methane emissions (kgs CO_2e per head per year)**	Methane emissions (kgs of CH_4 per head per year)	**Methane emissions (kgs CO_2e per head per year)**	Methane emissions (kgs of CH_4 per head per year)	**Methane emissions (kgs CO_2e per head per year)**
Cows		28		72	**2,016**	90	**2,520**	126	**3,528**
Calves	31.6	28	**885**	47	**1,316**	40	**1,120**	46	**1,288**
Cow-calf pairs	92.1	28	**2,579**						
Replace’t heifers	71.8	28	**2,010**	56	**1,568**	75	**2,100**	88	**2,464**
Bulls	87.1	28	**2,439**	75	**2,100**	94	**2,632**	121	**3,388**
Steers	71.8	28	**2,010**	47	**1,316**	56	**1,568**	50	**1,400**

Sources: See footnotes in table

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[116] M. Liebig et al., “Grazing Management Contributions to Net Global Warming Potential: A Long-Term Evaluation in the Northern Great Plains,” *Journal of Environment Quality* 39, no. 3 (2010).

[117] S. Kulshreshtha et al., “Economic and Greenhouse Gas Emissions Impacts of Doubling of Ofrage Area in Manitoba, Canada,” *Canadian Journal of Soil Science* (2016). Kulshreshtha et al. cite the IPCC.

[118] K. Ominski et al., “Estimates of Enteric Methane Emissions from Cattle in Canada Using the Ipcc Tier-2 Methodology,” *Canadian Journal of Animal Science* 87, no. 3 (2007).

[119] Ominski et al., “Estimates of Enteric Methane Emissions from Cattle,” 466.

[120] Ominski et al., “Estimates of Enteric Methane Emissions from Cattle,” 466.

Table 11-4: Beef: Total GHG emissions per kg of beef

Study	Type	Locations	GHG emissions
Legesse et al., 2015, "Greenhouse Gas Emissions of Canadian Beef Production in 1981 as Compared with 2011"	Modelling	Canada	2011: **12.0 kgs CO_2e per kg liveweight**, feedgrain production and farm inputs included.
Capper, 2011, "The Environmental Impact of Beef Production in the United States: 1977 Compared with 2007"	Modelling	US	2007: **17.9 kgs CO_2e per kg of processed beef**, feedgrain production and farm inputs included.

It is important to acknowledge that it is not just "factory farming," intensive livestock operations (ILOs), feedlots, or grain feeding that are causing the problems. While feedlots and grain feeding contribute to certain environmental problems (including massive CO_2 and N_2O emissions from upstream feed-grain production), it is the cow-calf sector and grass feeding that produces most of the methane emissions. An article by Beauchemin et al. reiterates this in its findings:

> *About 84% of enteric CH_4 was from the cow–calf system…, mostly from mature cows. In contrast to some perceptions, the feedlot system accounts for a relatively small fraction of enteric CH_4 from beef production. The lower CH_4 emission from this system is due mainly to its relatively brief duration and, to a lesser extent, to the use of grain-based finishing rations.*[121]

Estimates of cattle-facilitated soil carbon sequestration

Pastureland and rangeland can have high soil carbon sequestration rates relative to cropland. Reasons for this include that grazing-land grasses and other perennials allocate a greater proportion of plant biomass carbon to belowground growth, have a longer growing season, experience much less soil disturbance, and utilize water better. That said, soil carbon increases have limits, and carbon gain and carbon loss eventually reach equilibrium and the soil carbon sequestration effect slows then stops. Moreover, depending on the initial condition of the rangeland or pasture, there may be little sequestration potential—a given pasture may not provide a high rate of carbon sequestration if that land has not been cropped for long periods or if it has not been sub-optimally managed and, thus, carbon levels have never been depleted. As a rule, the amount of carbon that can be sequestered by adopting an improved grazing or cropping practice is equal to the amount that has been previously lost due to sub-optimum practices. To a great extent, sequestration is the repayment of a carbon debt.

Rotational grazing is one of several BMPs that can increase soil organic carbon. Rotational grazing involves subdividing a pasture with fences and intensively grazing small paddocks for a relatively short time—2 to 14 days—then moving the livestock and leaving the paddock to rest and regrow. A minimalist definition is "grazing management that defines reoccurring periods of grazing, rest, and deferment for two or more pastures."[122] Rotational grazing has both GHG emission reduction benefits and soil carbon sequestration benefits. Emissions can be reduced because rotational grazing gives livestock the opportunity to eat grass and legume forage when that forage is younger and lusher and this more-digestible feed lowers enteric methane emissions per unit of weight gain. Also, rotational grazing increases food availability for the cattle, further contributing to rapid weight gain. (The faster the gain the younger the animal is at slaughter and the lower its lifetime emissions.) Higher grass productivity can also be land-conserving: production of a

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[121] Beauchemin et al., "Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study," *Agricultural Systems* 103 (2010).

[122] D. Briske et al., "Rotational Grazing on Rangelands: Reconciliation of Perception and Experimental Evidence," *Rangeland Ecology & Management* 61, no. 1 (January 2008).

given amount of meat can occur on a smaller area, creating the potential to use some land for wildlife habitat, set-aside programs, or afforestation.

Rotational grazing can increase soil carbon gain. However, estimates of the rate and extent of that sequestration vary many-fold, so it is important to look at a number of studies. The literature also shows that *rainfall amounts and other weather factors are key determinants of soil carbon sequestration rates*, so it is important to look for studies applicable to the area in question. Finally, it is important to consider the *type* of study one is looking at. Some scientists measure carbon levels at a specific location. Others use computer *models* to project sequestration rates over large areas. Neither approach is inherently superior. Here, we look at a selection of results that attempt to answer the question: how much soil carbon sequestration might be accomplished by improved grazing management?

Grazing has strong advocates. Alan Savory, Gabe Brown, and Christine Jones are high-profile proponents of good grazing management. These people and others have done a great deal to help farmers understand how to use better practices to enhance soils, herd health, and returns. Some advocates, however, make outsized claims about grazing. Alan Savory, in a much-discussed 2013 TED Talk, claims that optimized cattle grazing techniques can reverse climate change. Going further, he claims that “if we do what I am showing you here, we can take enough carbon out of the atmosphere and safely store it in the grassland soils for thousands of years, and if we just do that on about half the world's grasslands that I've shown you, we can take us back to pre-industrial levels” of atmospheric greenhouse gases.[123] Savory is claiming that grazing soils can sequester, not only all of the carbon that has been released from grazing and cropland soils over the centuries, but also all the carbon that has been released from fossil-fuel burning. This is, of course, absurd.[124] This kind of overstatement shows why it is important to closely examine evidence from a wide range of scientists and experts.

Table 11-5, below, summarizes the results of 10 studies of the effects of improved grazing management on soil carbon sequestration. Some of these studies, in turn, are themselves reviews—analyses of many other studies on the same topic. If we look at that Table we see the wide range of estimates. Among the most optimistic assessments of soil carbon sequestration potential comes from a 2015 modelling study by Tong Wang and his coauthors. Their computer model suggests sequestration potential of **8,636 kgs CO_2e per hectare per year** in the southern US where cattle can graze on pasture and rangeland all year long. Their study looked at a change from heavily stocked continuous grazing (some would say overgrazing) to enhanced multi-paddock or rotational grazing. Thus, it probably reflects something approaching a maximum sequestration value for grazing-practice changes. Though the climate and landscape for this study are different than those that exist in much of Canada, it is included to show just how high estimates can go. These estimates come from a computer model, but one that was based on measurements at three actual ranches. For source information see Table 11-5.

Another study that calculated high sequestration figures was published in 2010 by Liebig et al. That study, based on actual experimental measurements showed a potential soil carbon sequestration rate of **1,700 kgs CO_2e per hectare per year** in the northern US (North Dakota) where cattle graze on pasture from mid-May to early October. In another journal article—a review and meta-analysis of 115 studies—Conant et al. quantified potential sequestration rates from “improved grazing” at **1,284 kgs CO_2e per hectare per year.** In another review of studies in several US states, Derner and Schuman found sequestration rates ranging from **0 to 1,101 kgs CO_2e per hectare per year.** Eagle, in reviewing several studies, calculated a range of

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[123] Allan Savory, *How to Fight Desertification and Reverse Climate Change*, TED Talks, 2013, http://www.ted.com/talks/allan_savory_how_to_green_the_world_s_deserts_and_reverse_climate_change?language=en; Allan Savory, “Transcript of ‘How to Fight Desertification and Reverse Climate Change,’” February 2013, http://www.ted.com/talks/allan_savory_how_to_green_the_world_s_deserts_and_reverse_climate_change/transcript.

[124] For some arguments from others who disagree with Savory, see M. Nordborg and E. Röös, *Holistic Management: A Critical Review of Allan Savory’s Grazing Method* (EPOK, 2016).

probable sequestration effects of rotational grazing on tame pasture of **-50 to 2,900 kgs CO_2e per hectare per year** and rotational grazing on *rangeland* of **-5,270 to 1,900 kgs CO_2e per hectare per year**. Several other studies, however, found **no significant differences** in soil carbon sequestration rates between continuous grazing and rotational grazing. For examples, see Manley and his coauthors, or Sanderman and his coauthors. David Briske is perhaps the most outspoken critic of rotational grazing as a "one best way" to manage pastures and rangeland. His opinions are summed up in a 2014 study in the journal *Agricultural Systems*. Briske writes that intensive rotational grazing "has been rigorously evaluated, primarily in the US, by numerous investigators at multiple locations and in a wide range of precipitation zones over a period of several decades. Collectively, these experimental results clearly indicate that IRG does not increase plant or animal production, or improve plant community composition, or benefit, soil surface hydrology compared to other grazing strategies (Briske et al., 2008, 2011)."[125]

Most useful for our purpose is a 2005 study that included Prairie-specific results that estimated that improving tame pasture by seeding a mixture of high-quality grasses and legumes and then grazing the land rotationally or continuously could increase the rate of soil organic carbon sequestration by **229 to 276 kgs CO_2e per hectare per year**.[126] Important to note, the main effect was from the seeding a grass-legume pasture mix, and the choice of rotational or continuous grazing had little additional effect.

Table 11-5: A selection of estimates of soil carbon sequestration from rotational grazing and other grazing management enhancements and BMPs

Study	Type	Locations	Based on	GHG emissions and carbon sequestration	Notes
Wang et al., 2015, "GHG Mitigation Potential of Different Grazing Strategies in the United States Southern Great Plains"[127]	Modelling and life cycle analysis (LCA), including indirect emissions from farm inputs, etc.	US Southern Great Plains (I.e., Texas and Oklahoma). Cattle graze on native pasture 100% of the year. Cottonseed meal is used as a protein supplement.	Modelled changes from light continuous (LC) or heavy continuous (HC) to multi-paddock (MP) (i.e., rotational) management strategies. Model based on actual measurements taken on 3 ranches.	Total emissions: 3,558 kgs CO_2e per head per year (LCA incl. farm inputs, etc.) **Sequestration** resulting from a change from heavy continuous to multi-paddock/ rotational: **8,636 kgs** C02e per hectare per year. Net emissions: -5,078 kgs C02e per hectare per year, i.e., net sequestration of 5 tonnes CO_2e per year.	Very high sequestration rates and net rates. This is partly as a result of the change from heavy continuous grazing to rotational/ multi-paddock. "[O]ur analysis indicated cow-calf farms converting from continuous to MP ['multi-paddock' ≈ rotational] grazing in SGP region are likely net carbon sinks for decades."
Liebig et al., 2010, "Grazing Management Contributions to Net Global Warming Potential: A Long-term Evaluation in the Northern Great Plains"[128]	Experimental measurements	US Northern Great Plains (I.e., North Dakota) Cattle graze from mid-May to early-October.	Native pasture and seeded forage pasture (crested wheat grass), and moderate grazing and heavy grazing. Based on steers grazing. 3 years of experimental data plus historical data.	Enteric methane emissions: 176 to 563 kgs CO_2e per hectare per year, depending on stocking density. **Sequestration**: **1,416 to 1,700 kgs** CO_2e per hectare per year.	Sequestration a result of grazing, not a change in practice. "We found all grazing treatments, representing long-term pastures of native vegetation and seeded crested wheatgrass, to be strong net sinks for SOC."
Conant et al., 2001, "Grassland Management and Conversion into Grassland: Effects on Soil Carbon"[129]	Review and meta-analysis		115 studies which included 336 experimental treatments. 31 of these studies focused on improved grazing.	**Sequestration**: **1,284 kgs** CO_2e per hectare per year for "improved grazing."	"Soil C content and concentration increased with improved management in 74% of the studies, and mean soil C increased with all types of improvement." "Soil C content and concentration increased, on average, for all types of management improvement"

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[125] David D. Briske et al., "Commentary: A Critical Assessment of the Policy Endorsement for Holistic Management," *Agricultural Systems* 125 (March 2014): 50–53, doi:10.1016/j.agsy.2013.12.001.

[126] Lynch et al., "Management of Canadian Prairie Region Grazed Grasslands," Table 5, 189.

[127] Wang et al., "GHG Mitigation Potential of Different Grazing Strategies in the United States Southern Great Plains."

[128] Liebig et al., "Grazing Management Contributions to Net Global Warming Potential."

[129] Conant, Paustian, and Elliot, "Grassland Management and Conversion into Grassland."

Study	Type	Locations	Based on	GHG emissions and carbon sequestration	Notes
Derner and Schuman, 2007, "Carbon Sequestration and Rangelands: A Synthesis of Land Management and Precipitation Effects."[130]	Review. Not a review of rotational grazing, but of changes in grazing practices more generally	US (Colorado, Wyoming, North Dakota, and Oklahoma)	Five studies on grazing practices cited.	**Sequestration: 1,101 kgs** C0$_2$e per hectare per year (Schuman et al., 1999, WY mixed grass prairie). **1,064 kgs** C0$_2$e per hectare per year (Frank, 2004, ND mixed grass prairie). **440 kgs** C0$_2$e per hectare per year (Derner et al., 1997, CO short grass prairie). **260 kgs** C0$_2$e per hectare per year (Reeder and Schuman, 2002, CO short grass prairie). **0 kgs** C0$_2$e (i.e., no significant change) (Fuhlendorf et al., 2002, OK mixed grass prairie).	
Manley et al., 1995, "Rangeland Soil Carbon and Nitrogen Responses to Grazing"[131]	Experimental measurement study	Wyoming	Measurements of soil organic carbon after 11 years (1982-1993) of continuous grazing, rotational grazing, and grazing exclusion.	No consistent differences in SOC between continuous or rotational grazing after 11 years. While rotational grazing did not sequester more carbon than continuous, *grazing in general* sequestered more in the upper 30 cms compared to ungrazed controls. But results were unclear if the entire 91 cm sampling depth is considered.	
Sanderman et al., 2015, "Impacts of Rotational Grazing on Soil Carbon in Native Grass-Based Pastures in Southern Australia"[132]	Experimental measurement study	Australia (southern)	Measurements in 12 rotationally grazed paddocks (6 to 79 hectares each) paired with nearby continuously grazed paddocks (17 to 2670 hectares).	No significant differences between rotationally and continuously grazed paddocks and remnant native vegetation.	"Detecting change in SOC has several added layers of complexity. As seen in this study and others…, the inherent variability in SOC within paddocks and across small regions makes detecting small but real improvements in SOC difficult."

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[130] Derner and Schuman, "Carbon Sequestration and Rangelands."

[131] J. T. Manley et al., "Rangeland Soil Carbon and Nitrogen Responses to Grazing," *Journal of Soil and Water Conservation* 50, no. 3 (May 1, 1995): 294–98.

[132] Jonathan Sanderman et al., "Impacts of Rotational Grazing on Soil Carbon in Native Grass-Based Pastures in Southern Australia," *PLOS ONE* 10, no. 8 (August 18, 2015): e0136157, doi:10.1371/journal.pone.0136157.

Study	Type	Locations	Based on	GHG emissions and carbon sequestration	Notes
Briske et al., 2008, “Rotational Grazing on Rangelands: Reconciliation of Perception and Experimental Evidence”[133]	Review/ synthesis based on 47 papers	Global	47 published studies	The paper does not state sequestration rates and is not focused on emissions and/or sequestration. Rather it states that plant production and other biological factors are not significantly different under rotational grazing.	“The preponderance of evidence generated from grazing experiments over the past 60 years has consistently indicated that rotational grazing is not superior to continuous grazing on rangelands…. This was true for the initial grazing experiments (Sampson 1951; Heady 1961), numerous investigations conducted throughout the 1970–1980s (O’Reagain and Turner 1992; Holechek et al. 2001; Norton 2003), and several rigorously designed recent investigations (Hart et al. 1993a, 1993b; Manley et al. 1997; Gillen et al. 1998; McCollum et al. 1999; Derner and Hart 2007). Yet, in spite of clear and consistent experimental evidence … rotational grazing continues to be promoted….”
Briske et al., 2014, “Commentary: A Critical Assessment of the Policy Endorsement for Holistic Management”[134]	Commentary				Intensive rotational grazing (IRG) “has been rigorously evaluated, primarily in the US, by numerous investigators at multiple locations and in a wide range of precipitation zones over a period of several decades. Collectively, these experimental results clearly indicate that IRG does not increase plant or animal production, or improve plant community composition, or benefit, soil surface hydrology compared to other grazing strategies….”
Lynch et al., 2005, “Management of Canadian Prairie Region Grazed Grasslands: Soil C Sequestration, Livestock Productivity and Profitability”[135]	Modelling	Canadian Prairies	GrassGro model simulation of various alternative management practices for cow-calf operations on prairie native rangelands and tame pastures	**Sequestration:** Reduced stocking on native rangelands **7 to 22 kgs** $C0_2e$ per hectare per year. Complementary grazing (moving cattle to different grasses that mature at different times) on native rangelands **97 kgs** $C0_2e$ per hectare per year. Reduced stocking on tame pasture **286 to 342 kgs** $C0_2e$ per hectare per year. Seeding grass-legume mixes and grazing rotationally or continuously **229 to 276 kgs** $C0_2e$ per hectare per year.	
Eagle et al., 2012, “Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature”[136]	Review	US (incl. Virginia, Wyoming, and Texas) and Canada (Alberta)	Five studies	**Sequestration:** Rotational grazing on tame pasture **-50 to 2,900 kgs** CO_2e per hectare per year. Rotational grazing on native rangeland **-5,270 to 1,900 kgs** CO_2e per hectare per year.	

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[133] Briske et al., “Rotational Grazing on Rangelands.”

[134] Briske et al., “Commentary.”

[135] Lynch et al., “Management of Canadian Prairie Region Grazed Grasslands.”

[136] Eagle et al., “Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States,” 38–42.

One must start by acknowledging the wide range of findings in the above-referenced scientific studies: from -5,000 to +8,000 kgs $C0_2$e per hectare per year. Next, one must acknowledge the importance of precipitation and growing-season length as important factors; the importance of initial land condition as a factor (i.e., the amount of soil carbon that has been lost); and the important differences between tame seeded pasture and native rangelands.

The balance between emissions and sequestration

Cattle methane emissions are fairly well understood and can be accurately measured or estimated (Tables 11-3 and 11-4). On the other side of the ledger, however, soil carbon sequestration effects that can result from enhanced grazing practices are not well understood and there appears to be little capacity to estimate their extent or duration beforehand. Indeed, the science is incomplete and often contradictory.

That said, carbon-sequestration *can* far exceed methane emissions. One cow-calf pair per 2 hectares (a moderate stocking rate) would emit the equivalent of about 1,300 kgs CO_2e per hectare per year. The best-case-scenarios for soil carbon sequestration model soil uptake of up to 8,636 kgs CO_2e per hectare per year—a clear climate win (though it may be the case that this sequestration rate aligns with a higher stocking rate and, thus, higher per-hectare emissions). Nonetheless, studies seem to support the contention that cattle can enable grassland to sequester more GHGs than cattle emit. But, again, how widespread this can occur and for how long cannot be determined from the studies. It is probably practical to assume that cattle *can* be GHG-neutral or -negative, but when considered over large areas, large amounts of time, and many management units, the vast majority of cattle-grassland systems, like the vast majority of herbivore-grassland systems in nature, will be significant net emitters. This does not mean there is no place for cattle in our climate-constrained future. Rather, like all parts of our food system and larger economy, cattle must be managed in ways that maximize their benefits while minimizing emissions. Given the massive emissions flowing from nearly all parts of our food, manufacturing, transport, communications, and other systems and given the difficulty of reducing those emissions, it would be surprising if our cattle-production systems were also not large net emitters and equally surprising if those emissions could be easily reduced.

Glossary

4R:	Fertilizer best management practices (BMPs) that seek to increase fertilizer-use efficiency and reduce emissions by placing fertilizer in the right place, at the right time, in the right amount, and by using the right fertilizer formulation or product.
BMP:	Best management practice—a superior method of farming that leads increases chances of benefits or desirable outcomes.
Carbon dioxide (CO_2):	One of the main three greenhouse gases and also one of the most important gases in the ecosystem. Trees and plants take in carbon dioxide to create their structure. Animals, including humans, breathe out carbon dioxide.
Carbon dioxide equivalent (CO2e):	A common unit of measure for diverse greenhouse gases that have different warming effects or strengths. For example, because the warming effect of nitrous oxide (N_2O) is 265 times as high as that of a comparable weight of CO_2, a tonne of nitrous oxide is recorded as 265 tonnes CO_2e. As an analogy, think of currencies; CO2e serves as the common currency for GHGs with different values.
CH_4:	See "methane."
CO_2:	See "carbon dioxide."
CO_2e:	See "carbon dioxide equivalent."
Greenhouse gas (GHG):	Gases that, when present in the atmosphere, cause Earth to retain heat energy and to warm. The three main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).
GHG:	See "greenhouse gas."
IPCC:	Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. Every five years the IPCC publishes a multi-volume assessment.
Methane (CH_4):	One of the three main greenhouse gases; a hydrocarbon; the primary constituent of natural gas; and the gas emitted from the mouths of ruminant animals (e.g., cows and sheep) when they digest grass.
N_2O:	See "nitrous oxide."
Nitrous oxide (N_2O):	One of the three main greenhouse gases and produced largely from nitrogen fertilizer use, manure storage and application, and fossil fuel combustion.
PFRA:	Prairie Farm Rehabilitation Administration—a federal agency in place from 1935 to 2012 that helped farmers protect soils and prevent erosion, develop water supplies, plant trees, and otherwise build landscape resilience to drought and adverse weather.

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A collaborative project of the National Farmers Union
the Prairie Climate Centre and SeedChange
with support from the Ivey Foundation