Environmental Defense Fund

Strategic Roadmaps for SBTi Forest, Land, & Agriculture Targets:

Prioritizing Action for Impact

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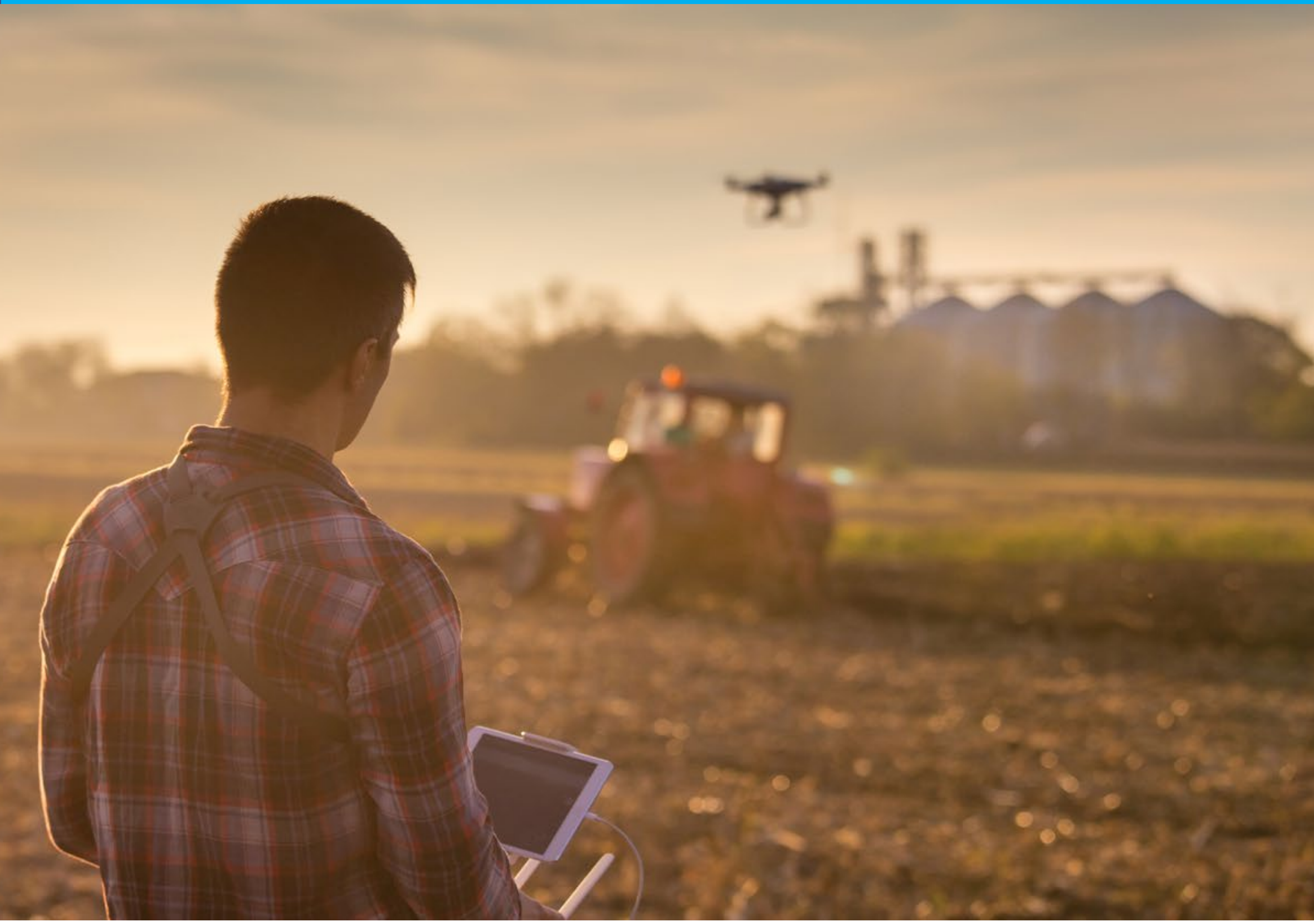


EXECUTIVE SUMMARY

SBTi Targets in the Context of Six Key Commodities

Given emissions reduction complexities unique to the Forest, Land, and Agriculture (FLAG) sector, the Science Based Target initiative (SBTi) has released guidance for companies to achieve yearly emissions reductions through commodity-specific or sector pathways. With that guidance's release, companies in the FLAG sector are now in the process of setting SBTi FLAG targets and identifying how they can most strategically move toward achieving those targets and drive meaningful impacts on climate.

Given the ambitious reductions set by the SBTi FLAG targets, this report examines the role of key greenhouse gases, identifies primary drivers of emissions, and recommends potential abatement solutions for six primary FLAG commodities – beef, dairy, chicken, corn, soy, and wheat in an effort to help companies develop plans to work towards achieving the target reductions. These six key commodities were selected from SBTi's guidance on eleven commodities due to their relative magnitude of GHG emissions, availability of relevant LCA data, and presence within the food systems of North America (for the purposes of this report, defined as the United States and Canada), the European Union, and United Kingdom – the in-scope regions for this report.

While SBTi FLAG commodity-specific targets are intensity goals (emissions per unit of product), companies must consider absolute emissions (total emissions of a system) in their strategies and long-term targets. Though absolute emissions are not captured in this analysis, it's necessary to consider that even with reduced emissions intensity, absolute emissions can still increase if the amount of production increases are proportionally greater than the emissions intensity reduction. Thus, it's essential to consider both emissions intensity and absolute emissions in a company's big-picture climate strategy.

Why a Gas-Specific Approach?

Breaking out emissions reduction targets and mitigation opportunities by greenhouse gas enables FLAG companies to better account for the different qualities of key agricultural greenhouse gases, carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). While these gases are often viewed through the lens of carbon dioxide equivalents (CO_2e), that limits the ability to properly account for the different characteristics of these gases, such as their differing global warming potentials (GWP) and atmospheric lifespans (how long they stay in the atmosphere). These factors influence the climate impact of and mitigation opportunities for a particular gas and are vital to consider when identifying the most strategic and effective opportunities to reduce near-term warming.

While emissions of all GHGs need to be sharply reduced, understanding the impacts and opportunities of rapid, near-term reductions in emissions of short-lived gases, like CH_4, is particularly important as it provides the best opportunity to avoid the worst impacts of climate change by mid-century.

Additionally, both CH_4 and N_2O have higher GWPs than CO_2, over the near- and long-term, meaning that for an equivalent amount of gas emitted, they create a greater amount of warming than CO_2. Thus, addressing key agricultural sources of these emissions can offer significant opportunities for impact.

Companies cannot afford to waste a moment in adopting solutions to make food production sustainable for years to come – the resilience of the agricultural system and its continued ability to supply food to a growing population on a finite land area is dependent on more strategic and prioritized climate action.

Act, Advocate, Advance

Achieving science-based FLAG targets will require a combination of solutions of various stages of commercial maturity.

Companies must ACT to implement scalable abatement solutions, ADVOCATE to reduce barriers to adoption of solutions, and ADVANCE promising solutions from R&D to commercialization.

These three action types must be pursued in tandem and in a way that accounts for the differences among agricultural greenhouse gases to unlock the full extent of emissions reduction necessary for target achievement and to deliver maximum climate impact. Supporting growers and ranchers in adoption of climate smart agriculture practices through technical support and financial incentives that make trialing and implementing solutions sets more practical, attractive, and less risky will be critical for companies to drive down emissions in their values chains and ultimately achieve their FLAG targets.

Key Opportunities by Subcategory

CATTLE: METHANE

For beef and dairy commodities, methane (CH4) is the leading constituent gas in both the regions examined in this report, North America and Europe, but also globally. In both regions, enteric fermentation is the primary emissions driver of methane; as a result, solutions mitigating enteric fermentation will be critical. 95% percent of the total methane emissions from beef are attributed to enteric fermentation, with the remaining 5% coming from manure management. Piloting enteric methane-reducing solutions and supporting innovation for solutions suitable for beef grazing systems will be necessary for managing methane.

Given that dairy operations often utilize confined spaces like barns and feedlots, and manure from dairy cattle is aggregated for management, intensity from manure emissions is greater than for beef operations on average. As a result, manure management contributes relatively more methane for this commodity when compared to beef – in North America, 25% of the total methane emissions from dairy are driven by manure management. Adopting solutions appropriate to farm scale will be key. For companies sourcing beef and dairy products from outside North America and Europe, improvements in animal health and addressing nutritional deficiencies are critical to reducing outsized CH_4 emissions intensities.

Figure 1: Cattle Summary

	ACT	ADVOCATE	ADVANCE
BEEF Primary GHG: Methane Primary Emissions Driver: Enteric Fermentation, with 84-95% of CH_4 emissions	**Pasture Management** Promote site assessments and implement practices	**Feed Additives** Advocate for efficient approval of safe products and government support of solutions implementation	**Additives & Other Products** Support additional research for high-impact solutions
DAIRY Primary GHG: Methane Primary Emissions Driver: Enteric Fermentation, with 73-88% of CH_4 emissions	**Manure Management** Determine best-fit solutions to minimize leakage **Feed Additives** Use approved products for enteric methane reduction		**Herd Management** Support and develop selective breeding programs for emissions reductions

POULTRY: CARBON DIOXIDE & NITROUS OXIDE

Emissions of carbon dioxide and nitrous oxide take precedence for poultry. For broiler chickens, carbon dioxide represents the primary constituent gas, driven by the production and provision of feed, commonly made from corn and soy crops. Roughly 75% of total carbon dioxide from poultry comes from feed, in both North America and Europe.

Direct energy use from operating poultry houses contributes the majority of the remaining 25% of CO2, representing another key driver to address.N2O emissions associated with poultry production arise mainly from feed production and litter management. Exploring feed alternatives, improving litter management, reducing energy use and utilizing renewable energy sources are all key opportunities for poultry.

Figure 2: Chicken Summary

CHICKEN	ACT	ADVOCATE	ADVANCE
Primary GHG: Carbon Dioxide Primary Emissions Driver: Feed, with 74-76% of CO_2 emissions	**Poultry House Mgmt.** Develop education programs on best practices	**Renewable Energy** Support renewable energy access across regions	**Feed Management** Support research and piloting of approved feed alternatives

CORN, SOY, AND WHEAT: NITROUS OXIDE

Across the crop commodities, nitrous oxide emerges as the most significant constituent gas. While carbon dioxide represents greater than 50% of the total emissions intensity for corn, soy, and wheat, it is field emissions that represent the single largest driver of a constituent gas – specifically nitrous oxide. For corn and soy, in both regions, field emissions are responsible for 100% of total nitrous oxide emissions (for wheat, field emissions drive 100% of N_2O in North America, but only 87% in Europe, with the remaining allocated to fertilizer production based on how the LCAs reported the emissions). It will be critical across the crop commodities to balance the significance of field emissions of N_2O with the major contributions of CO_2 from machinery, equipment, and fuel use, as well as fertilizer production.

Climate-smart agriculture practices, protective measures for soil health, and reduced fuel and energy use are all recommended solutions across crop commodities to improve resilience.

Figure 3: Crop Commodities Summary

CORN / WHEAT / SOY	ACT	ADVOCATE	ADVANCE
CORN Primary GHG: Nitrous Oxide Primary Emissions Driver: Field Emissions, with 100% of N_2O emissions WHEAT Primary GHG: Nitrous Oxide Primary Emissions Driver: Field Emissions, with 87-100% of N_2O emissions SOY Primary GHG: Nitrous Oxide Primary Emissions Driver: Field Emissions, with 100% of N_2O emissions	**Nutrient Management** Promote site-specific plans and use of precision technology **Intercropping** Practice intercropping to reduce need for chemical inputs	**Nutrient Management** Promote education on supplier-wide adoption of nitrogen management Develop internet infrastructure needed for precision technology **Intercropping** Promote education on the integration of non-crop plants (e.g. cover crops) for soil health	**Genetics** Support research and development on improved genetics **Nitrogen Fixing** Support research on compatible microbes and conduct tests

INTRODUCTION

FLAG's Capacity for Impact

The Forest, Land, and Agriculture (FLAG) sector, often referred to as the Agriculture, Forestry, and Other Land Use (AFOLU) sector, or the land sector, is critical to the sustainment of human life. FLAG is unique among its sector peers in that it includes the majority of non-ocean, natural carbon sinks, and is thus both a major source of emissions and a major source of potential removals. This sector will be critical to reducing emissions to limit global temperature increases to 1.5° Celsius above pre-industrial levels by 2050 as agreed upon under the 2015 Paris Climate Agreement.

FLAG also represents one of the greatest challenges to reducing global greenhouse gas (GHG) emissions. Estimates of emissions from this sector range from about 20 – 35% of global anthropogenic GHG emissions[1]. However, land represents both a source and a sink of emissions. Taking the land sink into account, SBTi estimates that the FLAG sector represents about 22% of net anthropogenic emissions globally, or ~13 $GtCO_2e$ per year, with nearly half resulting from agriculture and half from land use, land use-change, and forestry.[2] The sector's immense contribution to GHG emissions has been met with calls for action by FLAG companies of all sizes that are motivated by the potential environmental, social, and economic losses resulting from the immediate effects of a changing climate.[3, 4] Additionally, increasing public assistance for adopting reduced emissions technologies in the United States and Europe, changing regulations, and the prioritization of sustainability issues among consumers have evolved decarbonization from being solely a moral imperative to an economic one as well.[5, 6]

With the sector's capability and interest in reducing its climate change impacts, FLAG companies are eager to understand their own emissions, what decarbonization practices should be prioritized today, and what investments will be required to neutralize future emissions. As part of the larger effort to convert the Paris Climate Agreement's climate commitments to sector specific emissions reduction targets, the Science Based Target Initiative (SBTi) has released its net-zero emissions target for the FLAG sector. The SBTi FLAG Guidance requires companies to eliminate deforestation by 2025 and achieve yearly emissions reductions through either a sector- or commodity-specific basis.

SBTi developed its FLAG sector guidance by modeling the potential impacts of emissions reduction and carbon removal measures. Emissions reduction measures broadly include activities related to reduced land use change, agricultural improvements, diet shift, and reduced food loss and waste. Carbon removal measures broadly include activities related to restoring forests, improving sustainable forest management (SFM) and agroforestry, and enhancing soil carbon management. SBTi's modeled potential impact of these emissions reduction and carbon removal activities across all commodities and sector emissions is visualized below in Figure 4. While the potential emissions reductions used by SBTi to develop its FLAG targets have a significant amount of uncertainty in the literature, this report is not designed to question the FLAG targets but rather to help companies design emission reduction plans which include the best potential actions to achieve emissions reductions while scientific research continues to improve the understanding of the potential of these mitigation activities.

[1] *Emissions trends and drivers.* 2019. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg3/chapter/chapter-2/

[2] *The SBTi launches the world's first standard method to cover land-related emissions and removals*. (n.d.). Science Based Targets. https://sciencebasedtargets.org/news/the-sbti-launches-the-worlds-first-standard-method-to-cover-land-related-emissions-and-removals-2

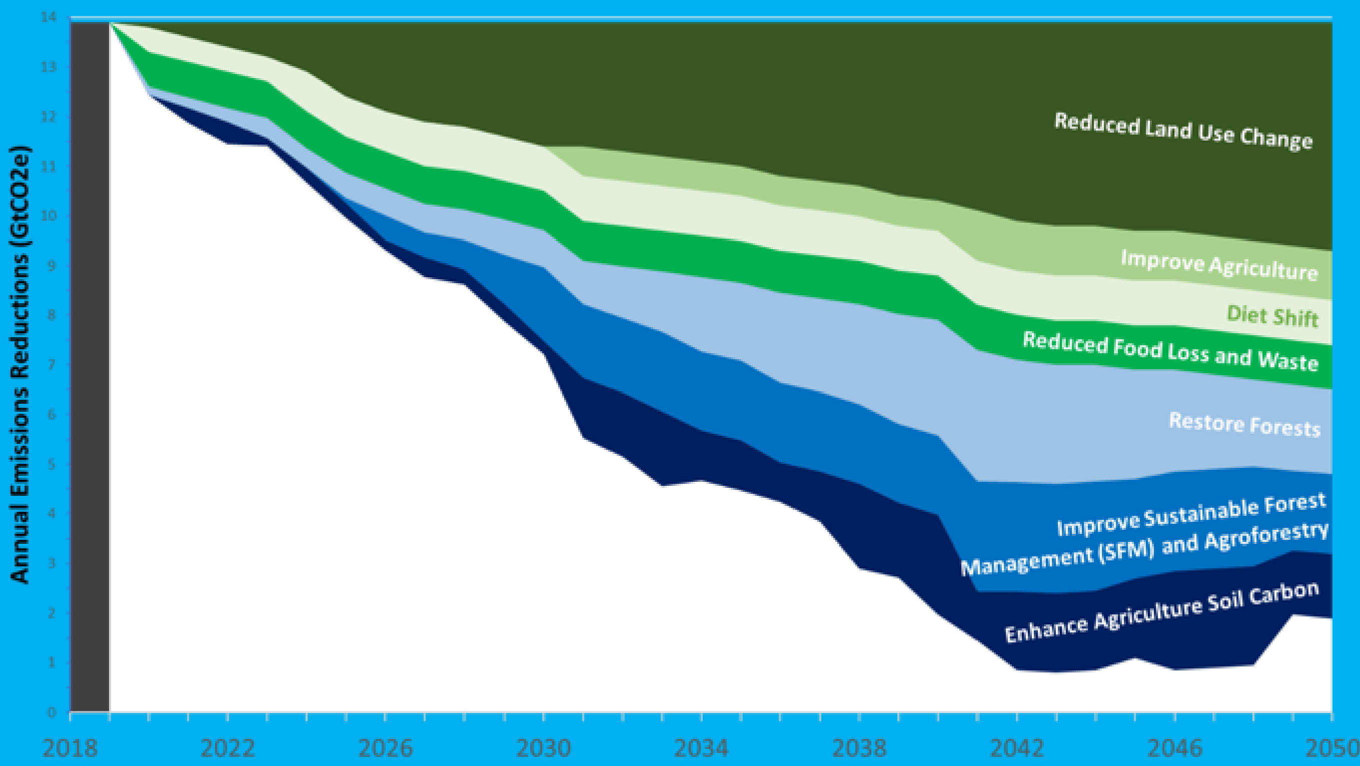
[3] (n.d.). *Climate Change*. General Mills: Climate Change. https://www.generalmills.com/how-we-make-it/healthier-planet/environmental-impact/climate-change

[4] EPA (n.d.). *Climate Impacts on Agriculture and Food Supply*. City of Chicago. https://climatechange.chicago.gov/climate-impacts/climate-impacts-agriculture-and-food-supply

[5] The White House (2022, August 16). *Inflation Reduction Act Guidebook*. White House: Clean Energy. https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/

[6] Deloitte UK (n.d.). *How Consumers are embracing sustainability*. Sustainability & Consumer Behaviour 2022. https://www2.deloitte.com/uk/en/pages/consumer-business/articles/sustainable-consumer.html

Figure 4: Analysis of Future FLAG Sector Emissions by Abatement Potential [Source: SBTi FLAG Tool]



Note: This figure is adapted from SBTi's model of annual emissions reduction which relies on assumptions to estimate the potential impacts of each abatement solution.

This report builds upon SBTi's FLAG guidance to define potential decarbonization pathways for six FLAG commodities in the United States, Canada, European Union, and United Kingdom: beef, dairy, poultry (specifically broiler chickens), corn, soy, and wheat.

These pathways were developed after conducting a meta-analysis of selected life-cycle assessments (LCAs) to determine the roles that nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) have on the underlying emissions drivers for each commodity relative to each gas' respective global warming potential (GWP). The LCA meta-analysis references are provided in the LCA Studies section of the Appendix.

SBTi's FLAG Target and the Role of Constituent Gases

The SBTi guidance for the FLAG sector is built on the most recent climate science*, allowing food and agriculture companies to identify the scale and pace of GHG emission reductions needed to align with the global targets set by the Paris Agreement. SBTi's FLAG guidance covers GHG emissions from FLAG designated companies, as well as companies where FLAG-related emissions comprise over 20% of their scope 1, 2, and 3 emissions.[7]

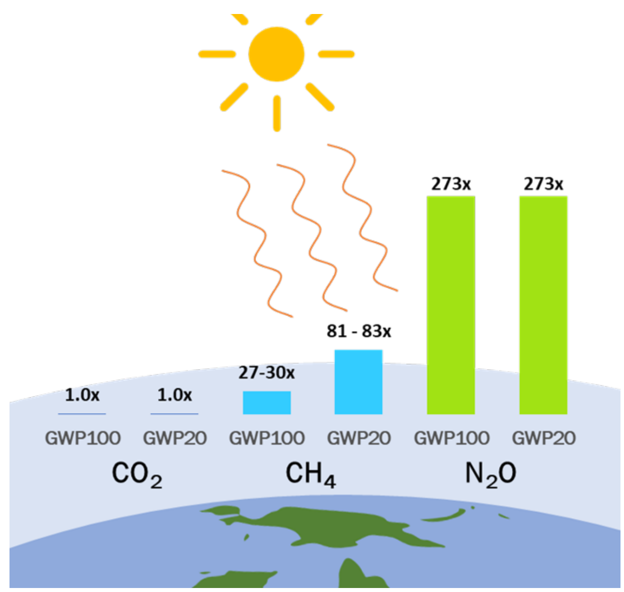
SBTi's FLAG guidance is an operational change for companies that fall in these two categories. Beyond setting an energy SBT, as many companies in the sector have already done, companies will need to define distinct baselines and targets for both their energy and FLAG emissions, respectively.[8] Instructions and considerations on how to set an energy SBT can found in the [SBTi Corporate Manual] and, for those required, instructions and considerations on how to set a FLAG SBT can refer to SBTi's FLAG guidance.

Within the FLAG sector, a notable portion of emissions come from methane (CH_4) and nitrous oxide (N_2O), which have their own global warming potentials (GWP) relative to carbon dioxide (CO_2).[9] Emissions baselines and targets are often reported using carbon dioxide equivalent (CO_2e) values, which translate the warming potential of non-carbon GHGs into the equivalent amount of carbon dioxide. CO_2e values standardize the GWP of a gas for comparison but can misrepresent the effect of short-lived climate pollutants (SLCPs) like CH_4.[10] SLCPs exist in the atmosphere for a shorter duration than CO_2 but can have an outsized warming impact. For example, for CH_4, the 100-year GWP is 28 times more potent than CO_2, but the 20-year GWP is closer to 85 times more potent.[11]

This difference matters for SLCPs, like CH_4 that persists in the atmosphere for about 12 years, because they are highly potent in that short period. Prioritizing cutting these emissions can influence the warming the planet will experience in the near-term and have significant implications for our agricultural system's continued resilience and ability to feed a growing global population. The meta-analysis performed in this report looked to understand the composition of the FLAG sector's current emissions, broken down by its primary GHGs, to better capture the nuance of these constituent gases and support prioritization of solutions to reduce emissions.

Understanding the role that these constituent gases are playing in baseline emissions of the sector is essential to define a decarbonization pathway, allowing for prioritization and sequencing of emissions reduction solutions over time. Companies can use the values published in this report as a benchmark to estimate the role constituent gases have in their own emissions footprints.

Figure 5: Relative GWP of Constituent Gases[9]



* The guidance references key studies utilized in the development of the FLAG commodity pathways, included: Smith et al. (2016), Roe et al. (2019), FAO GLEAM (2018), and the World Food LCA Database (WFLDB; Nemecek et al., 2019). For full references and additional details see the FLAG Methods Addendum.

[7] Anderson, C., Bicalho, T., Wallace, E., Letts, T., & Stevenson, M. (2022). *FOREST, LAND AND AGRICULTURE SCIENCE BASED TARGET-SETTING GUIDANCE*. Science Based Targets Initiative (SBTi). https://sciencebasedtargets.org/resources/files/SBTiFLAGGuidance.pdf

[8] (n.d.). *Companies Taking Action*. Science Based Targets. https://sciencebasedtargets.org/companies-taking-action

[9] Global Warming Potentials can be defined as how much energy an emission of 1 ton of a gas 'will absorb over a given period of time, relative to 1 ton of CO2'; these values allow the comparison of the emissions of various gasses and their estimated impact on global warming.

[10] (n.d.). *Global Warming Potentials (GWPs)/CO2-equivalent (CO2e) and the importance of time horizons.* Environmental Defense Fund. https://www.edf.org/sites/default/files/content/emission_equivalency_tool_documentation_methodology_23062022.pdf

[11] US EPA. (Last updated: 2023, April 18). *Understanding Global Warming Potentials*

Acknowledgement of Challenges when Setting FLAG SBTs

Because companies have varying levels of visibility into the emissions of commodities within their value chains, the process for setting FLAG SBTs can be complex. Additionally, there are a number of sources for guidance, tools, and resources that companies may leverage in the process of setting targets – which is tremendously useful and can also be complex to navigate. The below aims to provide some clarity into the tools available through SBTi as well as high-level considerations for navigating near-term commodity targets and long-term sector targets.

As companies initiate the process of setting SBTs, they must consider both near-term and long-term targets; near-term targets cover 5 to 10 years from the submission of the target, and long-term targets cover the total level of decarbonization by 2050 or sooner. At present, the SBTi FLAG Guidance stipulates that companies setting FLAG SBTs should use the SBTi FLAG tool for establishing near-term targets aligned with commodity pathways. However, long-term net-zero FLAG targets must be set using the SBTi Corporate Net-Zero Standard and Net-Zero Tool only.

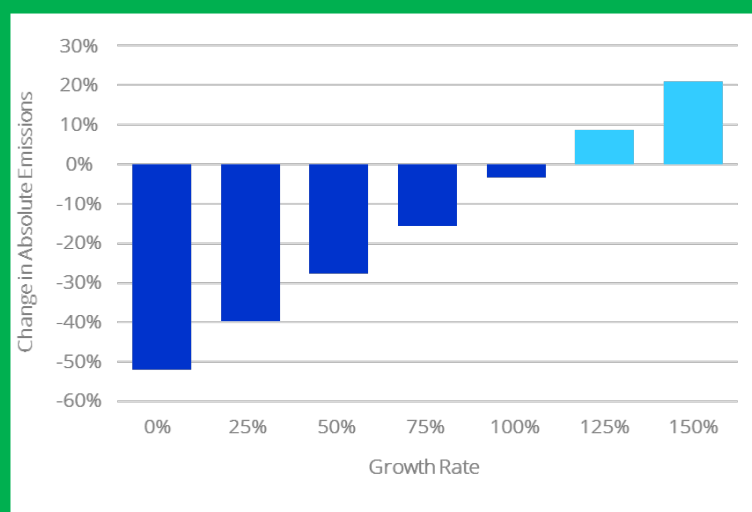
An additional layer of complexity lies in the distinction between emissions intensity and absolute emissions as related to target setting. Emissions intensities capture emissions per unit of product, while absolute emissions represent the overall emissions from a system.

When setting FLAG targets, the SBTi FLAG tool enables **near-term targets to be set based on emissions intensity** for commodities. The subsequent sections of this report focus on emissions reduction aligned with SBTi FLAG commodity intensity pathways, based on an analysis to show what intensity targets could resemble for the commodities in scope.

However, when using the SBTi Net-Zero tool **for long-term targets, companies will need to set a target for absolute emissions reduction**. For agriculture, the Net-Zero guidance requires an overall 72% absolute emissions reduction target relative to the base year across an organization's operations. Considering absolute emissions requires accounting for the growth associated with a system over time. Though absolute emissions are not captured in this analysis, it's necessary to consider that even with reduced emissions intensity, absolute emissions can still increase if production increases are proportionally greater than the emissions intensity reduction. Thus, it's essential to consider both emissions intensity and absolute emissions in a company's big-picture climate strategy.

Figure 6 below illustrates how various growth rates would impact the relationship between absolute emissions and emissions intensity for a generic "Commodity A" with a 52% emissions intensity target.

Figure 6: Impact of Growth Rate on Absolute Emissions



Between 100% and 125% growth, while emissions intensity targets are still achieved, **the absolute emissions of the system still increase** due to the growth in products. See appendix for more detail on analysis.

REPORT SCOPE

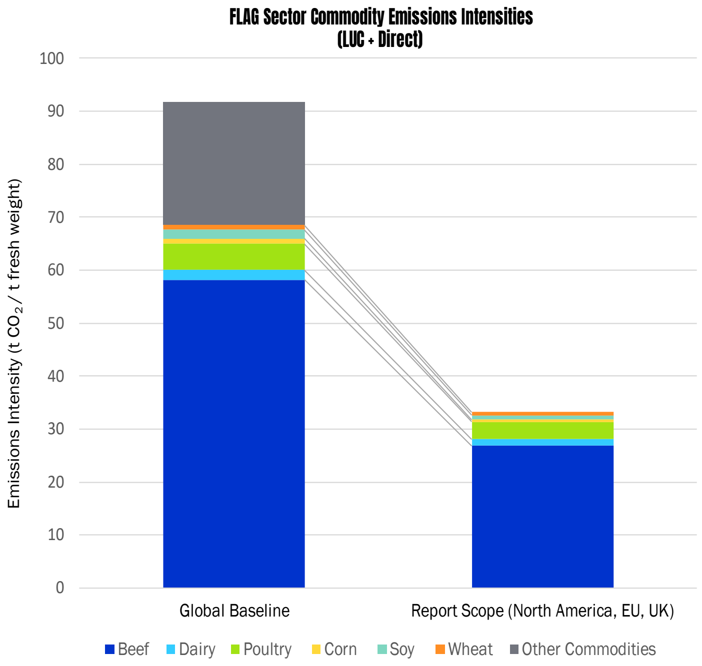
What is included in this report?

This report focuses on North America (including the United States and Canada for this scope), and Europe (including the European Union and United Kingdom). The report intends to illuminate decarbonization pathways within six key commodities: beef, dairy, poultry (specifically broiler chickens), soy, wheat, and corn. These commodities were selected from SBTi's guidance on eleven commodities due to their relative magnitude of GHG emissions, availability of relevant LCA data, and presence within the food systems of the in-scope regions. The other commodities referenced in SBTi's FLAG guidance still have a material role in the generation of GHG emissions and need to be considered by companies when setting FLAG SBTs.

The analysis of potential decarbonization pathways included within this report are fixated on current and expected future solutions within the farmgate. Some upstream emissions drivers (e.g., fertilizer production, feedstock creation), were assessed for inclusion on a commodity-specific basis (e.g., corn) when those activities could be appropriately accounted for and were material components of a commodity's lifecycle emissions. Though this report does not cover how companies will measure, monitor, report, and verify progress against targets, we acknowledge that this is a critical component.

While the primary audience of this report is companies that are setting or working to achieve science-based targets, they are often many steps removed from the farmers and ranchers who will need to implement practice changes to achieve emissions reductions or removals. These companies will not be able to make practice changes alone and will need to work with producers and partners in their value chains.

Figure 7: Report Scope [Source: SBTi FLAG Tool]



What is not included in this report?

Certain activities and geographic regions are outside of this report's scope due to a focus on prioritizing insights that maximize potential for decarbonization given limitations in data accessibility. Therefore, commodities beyond the six identified in the LCA meta-analysis; commodity production activities that occur outside the United States, Canada, European Union, and United Kingdom; decarbonization pathways and emissions outside of the farmgate (e.g., downstream transportation); and constituent gases beyond CO_2, N_2O, and CH_4 are not included within this report. Please also note that while the report includes some environmental justice considerations, it does not address the full complexity of environmental justice across the global landscape that remains imperative beyond this scope.

Scope of Land Use Change

In the review of emissions profiles across the six commodities, the LCA meta-analysis also evaluated land use change (LUC) emissions versus non-land use change emissions. LUC emissions are the greenhouse gas emissions associated with the conversion of an area's land from one use to another, including activities such as deforestation. These emissions can be difficult to account for over time, as the original land use change associated with an agricultural operation may have happened many years ago. As such, many of the LCAs selected for the meta-analysis did not include LUC emissions in scope due to the permissible time boundaries of the study. The challenges of historical accounting for LUC emissions, and the fact that these emissions are not clearly represented or discussed in LCAs, is a notable finding of this research effort. This underscores a difficulty for the sector at large – tracking and reporting LUC emissions is likely to be one of the most significant challenges companies will face as they set and work towards FLAG SBTs.

In order to evaluate and understand LUC emissions for this report, the LCA meta-analysis is supplemented by calculations of LUC emissions using the SBTi FLAG Tool, which provides default factors based on SBTi's data to support target setting. These default factors are provided by region (i.e., United States and Canada have separate default factors); when necessary, the analysis takes a weighted average approach to determining LUC emissions reduction based on the production of each region.

This is represented in SBTi FLAG Results tables for each commodity (Figures 10, 12, 14, 16, 18, and 20).

Likewise, removals were not included in the LCA meta-analysis, and default factors provided by the SBTi FLAG tool were used in the SBTi FLAG Results tables.

COMMODITY BASELINE EMISSIONS OVERVIEW

The meta-analysis supporting this report collated data from selected LCAs across North America, inclusive of the United States and Canada, and Europe to understand the emissions baselines, makeup of constituent gases, and primary emissions drivers across the six commodities. Baseline emissions were established on an intensity basis, shown in Table 1.

Table 1: Emissions Intensity Baselines

Commodity	Emissions Intensity Baseline for North America (2019)	Emissions Intensity Baseline for Europe (2019)
Beef	27.9 t CO_2e per t of Fresh Weight	26.1 t CO_2e per t of Fresh Weight
Dairy	0.95 t CO_2e per t of Fat & Protein-corrected Milk	1.18 t CO_2e per t of Fat & Protein-corrected Milk
Chicken	1.73 t CO_2e per t of Fresh Weight	2.51 t CO_2e per t of Fresh Weight
Corn	0.34 t CO_2e per t of Fresh Weight	0.34 t CO_2e per t of Fresh Weight
Soy	0.48 t CO_2e per t of Fresh Weight	0.26 t CO_2e per t of Fresh Weight^
Wheat	0.37 t CO_2e per t of Fresh Weight	0.35 t CO_2e per t of Fresh Weight

The meta-analysis provided the makeup of constituent gases for each emissions baseline, including methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). The results of the study revealed the main gas driving emissions for each commodity, as well as the proportion of the total emissions each gas constitutes.

Finally, the meta-analysis results included the primary drivers of emissions for each commodity. The emissions drivers are listed in Table 2.

Table 2: Emissions Driver Descriptions

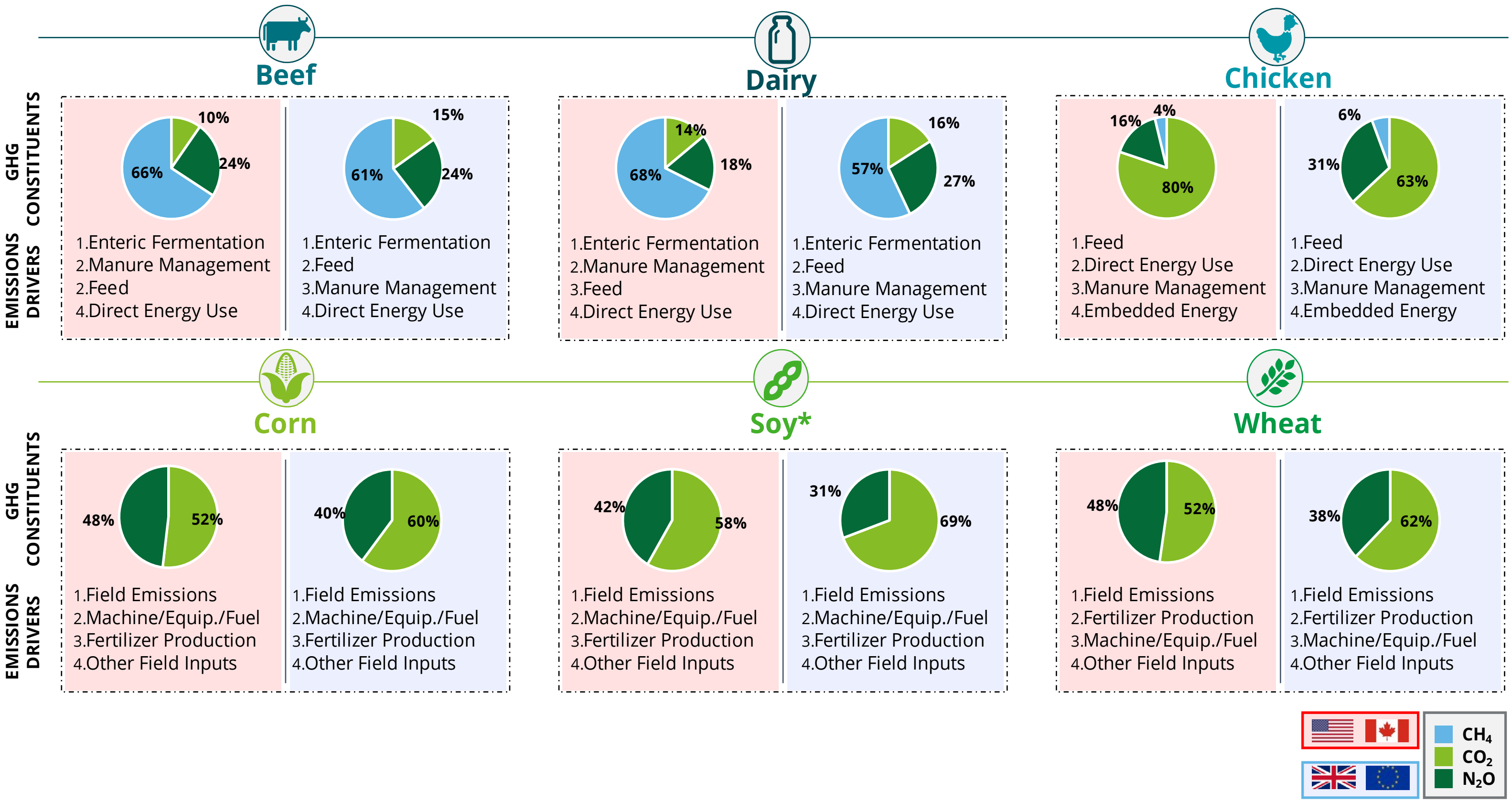
Driver	Description
Enteric Fermentation	Emissions resulting from the digestive process of ruminant animals such as cattle, which produce and emit methane as a by-product
Manure Management	Includes emissions from the management of livestock waste, including the livestock building, manure stores, manure treatment and manure spreading to land
Feed	Emissions from the production and transport of livestock feed, including purchased feed from upstream suppliers (e.g., corn, alfalfa, soy) and supplemental on-farm feed production[12]
Direct Energy Use	Emissions from fuels and electricity used in farm and ranch operations, transport vehicles, irrigation and feed processing
Embedded Energy	Covers the emissions associated with the input stage (i.e., chick life stage) for broiler chickens; this includes energy use from operating hatcheries, as well as transportation between hatchery and broiler sites
Field Emissions	In-field emissions associated with agricultural soils, fertilizer application, crop residues, and other human-driven on-farm activities (e.g., planting, harvesting)[13]
Machinery, Equipment, and Fuel Use	Emissions associated with the operation of heavy- and light-duty farm machinery, other equipment, and fuel use
Fertilizer Production	Pre-field emissions associated with the industrial production of fertilizer
Other Field Inputs	Pre-field emissions associated with the production and processing of other materials such as seeds and pesticides

[12] Rotz, C. Et. al. (2019, February). *Agricultural Systems*. Environmental footprints of beef cattle production in the United States,https://doi.org/10.1016/j.agsy.2018.11.005

[13] Koushki, R. Et. al. (2023, December). *Environmental Challenges*. Life cycle greenhouse gas emissions for irrigated corn production in the U.S. great plains https://doi.org/10.1016/j.envc.2023.100750

The emissions profiles and primary drivers for each commodity across both regions are summarized in Figure 8 below. As noted above, these emissions profiles only include non-land use change emissions due to lacking availability of LUC emissions data in the LCAs.[14]

Figure 8: Commodity Emissions by Constituent Gas and Primary Emissions Drivers



Summary Overview

For **cattle**, including beef and dairy commodities, methane is the leading constituent gas in both North America and Europe. In both regions, enteric fermentation is the primary emissions driver of methane; as a result, solutions mitigating enteric fermentation will be critical. However, important nuances distinguishing beef and dairy must also be kept top of mind. For example, 95% of the total methane emissions from beef are attributed to enteric fermentation, with the remaining 5% coming from manure management. In comparison, given that dairy operations often utilize confined spaces like barns and feedlots, and manure from dairy cattle is wet, intensity from manure emissions is greater than for beef operations on average. As a result, manure management contributes relatively more methane for this commodity when compared to beef – in North America, 25% of the total methane emissions from dairy are driven by manure management (vs. 5% in beef).

[14] Feed and Manure Management are tied for 2nd largest driver for Beef based on consensus across LCAs; for Soy, S. America used as a regional substitute for Europe

While methane represents the largest challenge for the cattle commodities, carbon dioxide and nitrous oxide take precedence for poultry and the crop commodities. For **broiler chickens**, carbon dioxide represents the primary constituent gas, driven by the production and provision of feed. Roughly 75% of total carbon dioxide from poultry comes from feed, in both North America and Europe. Direct energy use from operating poultry houses contributes the majority of the remaining 25% of CO_2, representing another key driver to address.

Across the **crop commodities**, nitrous oxide emerges as the most significant constituent gas. While carbon dioxide represents greater than 50% of the total emissions intensity for corn, soy, and wheat, it is field emissions that represent the single largest driver of a constituent gas – specifically nitrous oxide. For corn and soy, in both regions, field emissions are responsible for 100% of total nitrous oxide emissions (for wheat, field emissions drive 100% of N_2O in North America, but only 87% in Europe, with the remaining allocated to fertilizer production based on how the LCAs reported the emissions). It will be critical across the crop commodities to balance the significance of field emissions and N_2O with the major contributions of CO_2 from machinery, equipment, and fuel use, as well as fertilizer production.

Taken together, the meta-analysis results provide a foundation for understanding how to focus emissions reduction efforts for each commodity. Considering the most prevalent constituent gas emissions and the drivers of those emissions can inform recommended abatement solutions to prioritize and pursue. This report is intended to support companies' strategic prioritization of actions to reduce emissions within their value chains. It is essential that companies consider the unique aspects of their individual value chains when deploying solutions and determining what will be most appropriate and effective for their businesses and the regions within their footprint. Additionally, the deployment of one practice to reduce one source of greenhouse gas emissions can have the unintended consequence of increasing emissions elsewhere; while this report cannot capture all potential interactions, this is an essential consideration when implementing solutions.

The subsequent sections of this report unpack the solutions available and provide recommendations for each commodity.

CATTLE COMMODITIES

Overview

Cattle, which encompasses beef and dairy commodities for this report, is unique in that the vast majority of commodity emissions come from methane. Methane is both shorter-lived and 28 times more potent than CO_2 over a 100-year timeframe and over 80 times more potent over a 20-year timeframe, warranting prioritization of methane-specific emissions reduction in the near-term. [15,16] Methane reduction strategies should primarily target the cattle digestive process, known as enteric fermentation, as well as manure management.

The meta-analysis found manure management as a more intensive driver in the U.S. compared to Europe, due to a larger concentration of cattle per acre in the U.S. Conversely, feed emissions for cattle were relatively more intensive in Europe due to the transportation emissions embedded in the lifecycle from feed imports.

"Cattle is unique in that the vast majority of commodity emissions come from methane."

[15] IEA (2021), *Methane Tracker 2021*, IEA, Paris https://www.iea.org/reports/methane-tracker-2021, License: CC BY 4.0

[16] US EPA. (Last updated: 2023, April 18). *Understanding Global Warming Potentials*

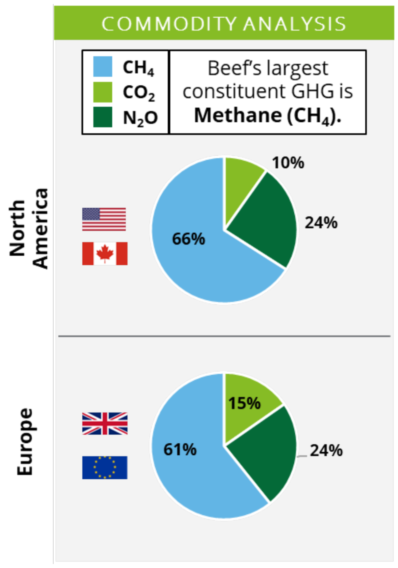
COMMODITY DEEP DIVE: BEEF

Overview

Beef cattle in the U.S. and EU typically graze on fields before continuing along the beef value chain, with most in the U.S. completing their final phase of production in feedlots for grain-finishing prior to slaughter.

While ruminant animals' digestive systems are biologically designed for grazing on harder to digest grasses, consuming that harder to digest plant material also typically results in more enteric fermentation emissions relative to feedlot rations. As a result, identifying and implementing effective solutions for methane reduction in grazing systems is essential, as this is where most enteric methane emissions are produced.

Figure 9: Beef Commodity Analysis



Beef emissions in context of SBTi FLAG targets

In the context of SBTi FLAG, companies working towards a beef commodity target would need to see reductions following the trajectory in Figure 10.

Figure 10: Beef SBTi FLAG Results

SBTi FLAG Results

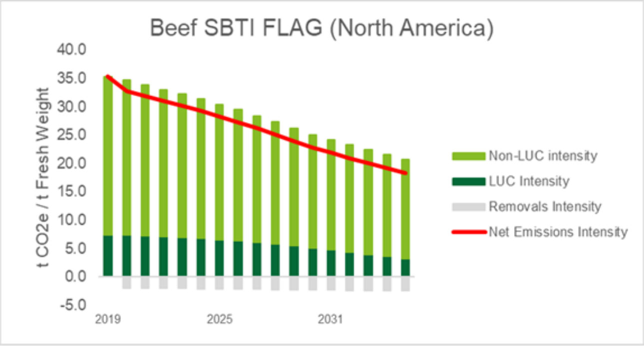
Emissions intensity units: t CO_2e / t Fresh Weight

North America

	Net Emissions Target		Non-LUC Emissions		LUC Emissions	Removals
	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	t CO_2e / t Fresh Weight
2019	35.30		27.87		7.44	0.00
2030	22.80	-35%	19.96	-28%	5.14	-2.30
2035	18.30	-48%	17.52	-37%	3.26	-2.48

Europe

	Net Emissions Target		Non-LUC Emissions		LUC Emissions	Removals
	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	t CO_2e / t Fresh Weight
2019	36.32		26.13		10.19	0.00
2030	26.08	-28%	21.77	-17%	7.04	-2.73
2035	21.78	-40%	20.26	-22%	4.46	-2.94



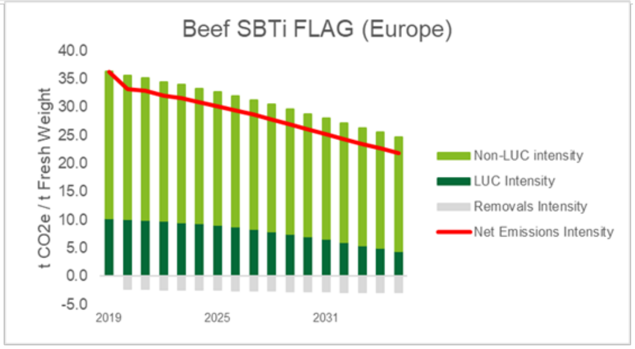


Figure 10 indicates that for beef, achieving the FLAG target for net emissions intensity by 2035 will require a 48% reduction of total emissions compared to the 2019 baseline for North America, and a 37% reduction compared to the 2019 baseline for Europe. The charts reflect the estimated reduction over time, with the red "Net Emissions Intensity" line showing the target, the light green bars showing the reduction in non-land use change emissions intensity, and the dark green bars showing land use change emissions intensity. The gray bars represent the estimated carbon removals. Potential carbon removal activities include soil sequestration on farm and pasture, conservation set-asides, agroforestry, silvopasture, and biochar. Carbon removal activities are an important component of what the FLAG sector will contribute to a 1.5C future.

For this reason, removals activities are required in FLAG. Further, these removals are from in-supply chain actions; removals from outside of supply chain activities (i.e., offsets) are not included in FLAG.

Achieving the targets outlined above will require addressing and prioritizing by greenhouse gas and emissions driver. For North American and European FLAG companies with beef in their value chains, **methane plays a critical role to achieving their commodity intensity targets. Reductions from the primary emissions driver, enteric fermentation, are likely to make up 15-20% of required annual intensity reductions by 2035**, **based on the average baseline emissions, required rate of reduction from SBTi FLAG targets, and an LCA meta-analysis of abatement opportunities.**

BY-GAS ABATEMENT OPPORTUNITIES

Table 3 below summarizes the breakdown of greenhouses gases and primary drivers of emissions for beef, as well as steps companies can take to reduce those emissions through a gas-specific approach.

Table 3: Beef Abatement Opportunities

Greenhouse Gas	Primary Emissions Driver	North America		Europe		Recommended Abatement Actions		
		% emissions from Gas	% total emissions	% emissions from Gas	% total emissions	ACT *Implement & scale today*	ADVOCATE *Set the foundation for tomorrow*	ADVANCE *Innovate to close the gap long-term*
Methane	**Enteric Fermentation**	95%	64%	84%	55%	**Pasture Management** Conduct ecological site assessments to inform an efficient grazing plan with optimized stocking rates Incorporate legumes and tannin-rich plants as compatible **Feed Additives** Add plant oils, such as olive, sunflower, or linseed, to diets	**Feed Additives** Vocalize the need for an accelerated regulatory approval process for safe and effective products	**Additives & Other Products** Support innovative research into solutions suitable for grazing environments **Herd Management** Research, develop, and offer selective breeding programs that include emissions measurement requirements and account for health and biodiversity implications
Nitrous Oxide	**Manure management**	55%	16%	40%	19%	**Manure Management** Employ best practices such as manure acidification, regular removal, and additives to reduce ammonia leakage		**Manure Management** Support research for innovative manure collection, treatment, and reuse technologies
	Feed	43%	13%	21%	23%	*See Row Crop Sections, which share recommendations for the commodities used as Feed for cattle*		
Carbon Dioxide	**Direct Energy Use**	75%	7%	45%	3%	**Renewable Energy** Utilize renewable energy sources for beef production where available today	**Renewable Energy** Lobby for increased access to renewable energy across regions	**Renewable Energy** Support and invest in advancements in renewable energy technologies
	Land Use / Land Use Change	*Emissions profiles only include non-land use change emissions due to lacking availability of LUC emissions data in the LCAs*				**Pasture Management** Develop standardized indicators of land degradation to improve grazing plans	**Grassland Conservation** Strengthen key programs supporting grasslands protection in the upcoming US Farm Bill	

Note: The "percent emissions from gas" columns highlight what percentage of all of the emissions from the row's specific constituent gas this primary emissions driver makes up, for North America and Europe each in their respective columns. The "percent total emissions" columns demonstrate what percentage that particular emissions driver makes up of the commodity's total emissions, for North America and Europe each in their respective columns

Additional considerations on key recommendations, particularly targeted to reducing methane as the largest constituent gas for beef, are detailed below.

Pasture Management

FLAG companies can support inclusion of key land management factors in grazing plans aimed at improving forage efficiency to reduce grazing methane emissions intensity. Elements to consider in land management include

- The optimization of the stocking rate, or the number of animals grazing on an area of land at any given time, as high stocking rates can lead to overgrazed pastures and thus land degradation. If grazing rates are above the carrying capacity of the grassland, soil organic carbon will be depleted.
- Consider native species, soil type, and other ecological traits to effectively determine stocking rates that allow for restoration of native vegetation.
- The grazing plans should account for site-specific characteristics that harmonize with the existing ecosystem. While highly productive and digestible grass species can reduce CH_4 emissions intensities in pastures, the replacement of native vegetation suppresses biodiversity and could trigger the loss of interconnected ecosystem services, once again leading to degraded grazing land.[17]
- The compatibility of grazing lands with legumes and tannin-rich plants that reduce methane intensity of enteric fermentation.

Grazing may offer a means of keeping native grasslands intact by preventing land conversion to alternative uses that would lead to carbon losses. Protection of grasslands is an essential lever of FLAG sector decarbonization and therefore should be recognized in EU and U.S. policy. Advocacy for incentive programs such as the USDA Conservation Reserve Program can also expand grower cost-share opportunities for operational expenses associated with grazing improvements.[18]

While maintaining healthy grasslands, improving degraded grasslands, and preventing their conversion can support continued carbon storage, land management and avoided land use change are near-term opportunities that can offer co-benefits but do not offer significant potential for the emissions reductions that will be essential to lowering beef's footprint in alignment with climate targets.

Feed additives & other products

In addition to grazing diets, feed additives and other methane reducing or inhibiting products can be given to cattle to specifically target methanogens in the digestive process. Methane-reducing products fall across a spectrum of commercial readiness, and ensuring both safety and efficacy of these novel products will be essential to their uptake. Dietary lipids such as olive, sunflower, and linseed oils are the most viable for immediate-term use and have proved minimal effect on ruminal pH and other health factors while decreasing daily methane emission by an average of 12 to 24% for beef cattle.[19] These lipids can be used to supplement beef cattle diets in the finishing phase as a component of the concentrate-based diets introduced to cattle once in the feedlot.

While the incorporation of 3-nitrooxypropanol (3-NOP, known commercially as Bovaer) into cattle diets has been found to reduce CH_4 emissions to a lesser degree in beef cattle relative to dairy cows, 3-NOP has surfaced as a particularly promising feed additive for both cattle types, averaging a 30% decrease in CH_4 production with reductions as high as 82% in some cases.[20] The methane inhibitor has been approved in many countries including Brazil, Chile, Australia, and Canada, and approved only for dairy cattle by the European Food Safety Authority. It has yet to receive final approval for either cattle type in the United States. Scientists have touted 3-NOP for its minimized disruption to cattle and human health combined with its outsized emissions impacts relative to other feed additives, warranting further research on its effects and dedicated advocacy to accelerate the market approvals process for both beef and dairy cattle for such products.

[17] Cezimbra, I. Et. al. (2021, August 1). *Science of The Total Environment*. Potential of grazing management to improve beef cattle production and mitigate methane emissions in native grasslands of the Pampa biome.https://doi.org/10.1016/j.scitotenv.2021.

[18] Lark, T. (2020, September). *Land Use Policy*. Protecting our prairies: Research and policy actions for conserving America's grasslands. https://doi.org/10.1016/j.landusepol

[19] Arndt, C Et. al. (2022, July 18). *Journal of Dairy Science*. Symposium review: Effective nutritional strategies to mitigate enteric methane in dairy cattle. https://doi.org/10.316

[20] Yu, G. Et. al (2021, December 13). *Animals*. A Review of 3-Nitrooxypropanol for Enteric Methane Mitigation from Ruminant Livestock

In addition to supportive policy for getting safe and effective products on market, continued innovation for methane inhibiting products will be essential to reducing beef sector emissions. The majority of methane in the beef life cycle comes from phases in which the cattle are grazing, and currently or soon-to-be-available solutions are primarily suitable for systems in which cattle are fed in a central location, such as with feed lots or dairy systems. Solutions that are effective and suitable for grazing environments will be needed to address this substantial portion of the beef emissions footprint and may take the form of slow-release boluses, vaccines, or other methods that do not require frequent incorporation into feed rations.

Herd management: Selective breeding

Selective breeding of beef cattle can be done to improve animal productivity, which in turn improves emissions intensity. Companies can adopt and offer selective breeding programs as a service to farms and ranches, and these offerings can also be used to incentivize emissions tracking as a part of productivity performance measurement. A more innovative - and less explored - form of herd management is genomic selection. Whereas selective breeding entails a gradual process of favoring the reproduction of more efficient cows of the same breed, genomic selection employs cross-breeding to introduce faster genetic progress towards enteric fermentation efficiency. However, phenotyping techniques and big data applications are needed to understand the related biodiversity and animal welfare implications.[21]

NOTABLE CONSIDERATIONS

In some regions outside North America and Europe, strides in animal health & feed management still can be made to address nutritional deficiencies and reduce emissions intensity. While North America and Europe are generally considered to achieve efficient cattle diets, abatement actions altering grazing, feed, and especially breeding management practices should test for impacts to animal health and welfare before scaling to industrial levels.

[21] Stranden, I. Et. al (2022, December). *Animal*. Animal board invited review: Genomic-based improvement of cattle in response to climate change. https://doi.org/10.1016/j.animal.2022.100673

COMMODITY DEEP DIVE: DAIRY

Overview

While dairy cows are less emissions-intensive than pasture-raised beef cattle, they are often kept in confined spaces like barns and feedlots that warrants a relatively greater focus on manure management practices as a key opportunity to reduce both methane and nitrous oxide emissions in dairies now.

When considering available practices, it is also essential to assess and manage potential negative community impacts related to manure management systems.

Dairy emissions in context of SBTi FLAG targets

To contextualize for SBTi FLAG, companies working towards a dairy commodity target would need to see reductions following the trajectory outlined in Figure 12 below.

Figure 11: Dairy Commodity Analysis

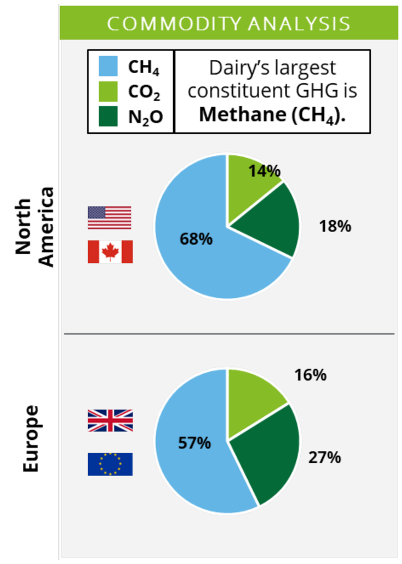
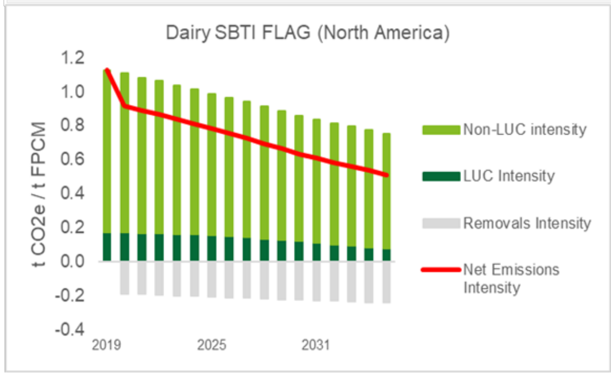


Figure 12: Dairy SBTi FLAG Results

SBTi FLAG Results

Emissions intensity units : t CO_2e / t Fat & protein corrected milk

Region	Year	Net Emissions Target: t CO_2e / t FPCM	Net Emissions Target: % reduction from baseline	Non-LUC Emissions: t CO_2e / t FPCM	Non-LUC Emissions: % reduction from baseline	LUC Emissions: t CO_2e / t FPCM	Removals: t CO_2e / t FPCM
North America	**2019**	1.13		0.95		0.17	0.00
	2030	0.63	-44%	0.74	-22%	0.12	-0.23
	2035	0.51	-55%	0.68	-29%	0.08	-0.24
Europe	**2019**	1.61		1.18		0.43	0.00
	2030	0.80	-50%	0.95	-19%	0.30	-0.45
	2035	0.58	-64%	0.87	-26%	0.19	-0.48



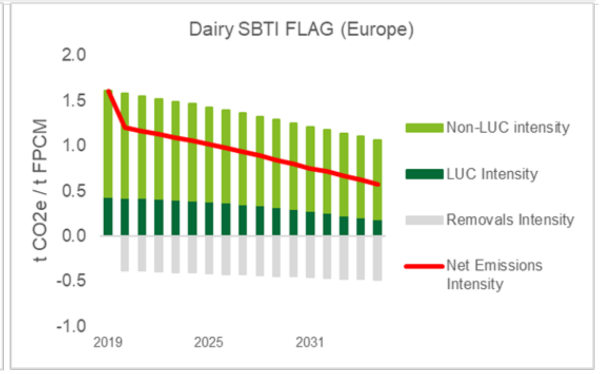


Figure 12 shows that for dairy, achieving the FLAG target for net emissions intensity by 2035 will require a 55% reduction of total emissions compared to the 2019 baseline for North America. Conversely, a 64% reduction compared to the 2019 baseline will be required for Europe. The charts illustrate the estimated reduction over time, with the red "Net Emissions Intensity" line showing the target, the light green bars showing the reduction in non-land use change emissions intensity, and the dark green bars showing land use change emissions intensity. The gray bars below the chart represent the removals required for the FLAG targets for dairy, inclusive of in-supply chain activities.

Achieving the targets outlined above will require addressing and prioritizing by greenhouse gas and emissions driver. For North American and European FLAG companies with dairy in their value chains, **methane plays a critical role to achieving their commodity intensity targets. Reductions from the primary emissions driver, enteric fermentation, are likely to make up 15-20% of required annual intensity reductions by 2035**, **based on the average baseline emissions, required rate of reduction from SBTi FLAG targets, and an LCA meta-analysis of abatement opportunities.**

BY-GAS ABATEMENT OPPORTUNITIES

Table 4 below summarizes the breakdown of greenhouses gases and primary drivers of emissions for dairy, as well as steps companies can take to reduce those emissions through a gas-specific approach.

Table 4: Dairy Abatement Opportunities

Greenhouse Gas	Primary Emissions Driver	North America		Europe		Recommended Abatement Actions		
		% emissions from Gas	% total emissions	% emissions from Gas	% total emissions	ACT *Implement & scale today*	ADVOCATE *Set the foundation for tomorrow*	ADVANCE *Innovate to close the gap long-term*
Methane	Enteric Fermentation	73%	51%	88%	51%	**Feed Additives** Add plant oils, such as olive, sunflower, or linseed, to diets as well as approved products	**Feed Additives** Vocalize the need for an accelerated regulatory approval process for safe and effective products	**Additives & Other Products** Support innovative research into methane reduction solutions **Herd Management** Research, develop, and offer selective breeding programs that include emissions measurement requirements and account for health and biodiversity implications
Methane	Manure Management	26%	27%	11%	18%	**Manure Management** [For large farms] Install anaerobic digesters and require maintenance training [For small farms] Determine best-fit storage practice and train on leakage prevention [For food production companies] Implement treatment, storage, and application education across supply chain [For all types] Employ best practices such as manure acidification, regular removal, and additives to reduce ammonia leakage		**Manure Management** Support research for innovative manure collection, treatment, and reuse technologies
Nitrous Oxide	Manure management	44%		39%				
Nitrous Oxide	Feed	49%	16%	59%	28%	*See Row Crop Sections, which share recommendations for the commodities used as Feed for cattle*		
Carbon Dioxide	Direct Energy Use	47%	6%	26%	4%	**Renewable Energy** Utilize renewable energy sources for dairy production where available today	**Renewable Energy** Lobby for increased access to renewable energy across regions	**Renewable Energy** Support and invest in advancements in renewable energy technologies

Note: The "percent emissions from gas" columns highlight what percentage of all of the emissions from the row's specific constituent gas this primary emissions driver makes up, for North America and Europe each in their respective columns. The "percent total emissions" columns demonstrate what percentage that particular emissions driver makes up of the commodity's total emissions, for North America and Europe each in their respective columns

Additional considerations on key recommendations, particularly targeted to reducing methane as the largest constituent gas for dairy, are detailed below.

Manure management

Farm scale is often a significant determinant of what manure management solutions are most feasible:

- **Small farms** can store manure through a variety of methods, such as dry stacking facilities consisting of an impervious floor (usually made of concrete) sloped for drainage towards a vegetated filter strip and containment walls to allow piling. An even cheaper option is stockpiling manure and soiled livestock bedding under a sealed tarp to keep out rain and prevent methane leakage. A more intensive manure management option growing in popularity is the composting of manure into a marketable fertilizer product, which requires careful monitoring, mixing, and aeration.[22]
- **Larger farms** can also install anaerobic digesters to convert manure into biogas, which can then be treated and sold as electricity. It is important to note that the use and sale of biogas is only a net positive for the climate when it is taken from sources currently leaking methane into the atmosphere, such as manure, landfills without flares, and wastewater treatment plants. Furthermore, digesters remain prone to methane leakage—if improperly maintained, a leaky digester yields significantly reduced environmental benefits. The conversion of manure biogas to renewable energy has yet to reach its full potential of revenue generation for farms, and recognition is needed by methane trading systems and the Low Carbon Fuel Standard to further reward the use of biogas for on-farm electricity use over its sale for fossil fuel.
- As manure contains ammonia as well as methane emissions, **farms of all sizes** can employ a set of best practices such as manure acidification, scraping and removing manure regularly, covers, and manure additives to reduce ammonia leakage from manure into the atmosphere. Manure is usually applied to crops as a fertilizer but must adhere to specific guidelines to prove economically and environmentally beneficial. Manure can be more costly to transport than chemical fertilizers, and overapplication of nutrients relative to crop needs can result in higher N2O emissions and leaching to ground water as nitrate. At the farm level, practices such as the injection of manure into the ground versus a broad spray application, as well as splitting applications between fall and spring rather than a single fall application can reduce risk of unused nutrient runoff. Application of manure in the fall can result in large losses of nitrogen to the environment and application should follow recommendations to reduce losses[23]. At the industry level, advances in manure collection and treatment technologies must continue advancing to reduce transport costs while identifying alternate marketable uses for excess manure.

The Dairy Methane Action Alliance

Recognizing the significant role of the food sector in reducing global methane emissions, Environmental Defense Fund has convened the Dairy Methane Action Alliance (DMAA), a global initiative to accelerate action and transparency on methane across the dairy sector.

Inaugural signatory companies – Bel Group, Danone, General Mills, Kraft Heinz, Lactalis USA (a U.S. affiliate of Lactalis Group), and Nestlé – commit to annually account for and publicly disclose methane emissions within their dairy supply chains, and to publish and implement a comprehensive methane action plan by the end of 2024.

In joining DMAA, these corporations have stepped forward to set a new standard for accountability, transparency, and ambitious climate action within the food industry.

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[22] Bollwahn, S. (2014, August 25). *Michigan State University.* Storing manure on small farms – deciding on a storage option. https://www.canr.msu.edu/news/storing_manure_on_small_farms_deciding_on_a_storage_option

[23] Michigan Farm Bureau (2023, September 28). *Michigan Farm News.* What to remember about fall manure applications. https://www.michiganfarmnews.com/what-to-remember-about-fall-manure-applications

Feed additives

A menu of solutions exists to mitigate emissions intensity associated with both feed digestibility (e.g., fat and tannin supplements) and general optimization (e.g., sourcing feed locally), but not all are commercially scalable as of today. 3-nitrooxypropanol (3-NOP) has been recently approved in Canada and for use in dairy cows by the European Food Safety Authority, but has suffered from years of regulatory reviews in the United States due to its classification as an animal drug (rather than feed additive). Its 30% average reduction potential is significant and merits dedicated advocacy to accelerate the market approvals process for such products. Red seaweed poses a potentially even more impactful feed additive, boasting enteric methane reductions over 80% in studies[24], but requires further research into its effects on human and cattle health before it can be deemed as a safe abatement pursuit.

Herd management

Selective breeding favoring lower variations in dairy cow methane emission intensity is a cost-effective, permanent, and cumulative solution that can be taken today. Studies predict the solution's efficacy can be nearly doubled if given economic weight. This can be done by advocating for the inclusion of methane intensity as an included trait in jurisdictional breeding goals, which have traditionally promoted traits such as milk yield, longevity, health, fertility, and feed efficiency.[25] To fully achieve selective breeding impact, dairy cows must be phenotyped and genotyped at scale to provide reliable methane data. As methane efficiency is tied with animal productivity, companies can begin recording methane data as a required metric when offering selective breeding services to farms.

NOTABLE CONSIDERATIONS

- In most cases, anaerobic digesters remain unaffordable for smaller farms that do not produce enough methane to justify high upfront investment costs.
- Animal health and nutrition have still not reached the ceiling of efficiency improvements, especially on a global scale, and should continue to be included as primary criteria for measuring the efficacy of feed management practices.
- Before scaling any shifts in feed diet, it is crucial to understand how these shifts will affect the balance of energy, protein, fiber, and other nutrients affecting milk production and cow health. For example, increasing the amount of concentrate in feed improves feed efficiency, but detrimentally affects cows' rumen pH and liver.

[24] Roque, B. (2021, March 17). *PLOS ONE.* Red seaweed (Asparagopsis taxiformis) supplementation reduces enteric methane by over 80 percent in beef steers. https://doi.org/10.1371/journal.pone.0247820

[25] Haas, Y. et. al. (2021, December). *Animal.* Selective breeding as a mitigation tool for methane emissions from dairy cattle. https://doi.org/10.1016/j.animal.2021.100294

COMMODITY DEEP DIVE: POULTRY

Overview

Poultry in the context of this report refers to broiler chickens, which are bred and raised specifically for meat production. The production of most broiler chickens takes place in large commercial operations, which are widespread given high demand – chicken is the most highly consumed animal protein in the United States.

For poultry, the predominance of methane emissions associated with cattle commodities is replaced with carbon dioxide emissions from poultry houses and feed production, and ammonia emissions from manure that can convert to nitrous oxide.

Poultry emissions in context of SBTi FLAG targets

To put this in the context of SBTi FLAG, companies working towards a poultry commodity target would need to see reductions following the trajectory outline in Figure 14 below.

Figure 13: Poultry Commodity Analysis

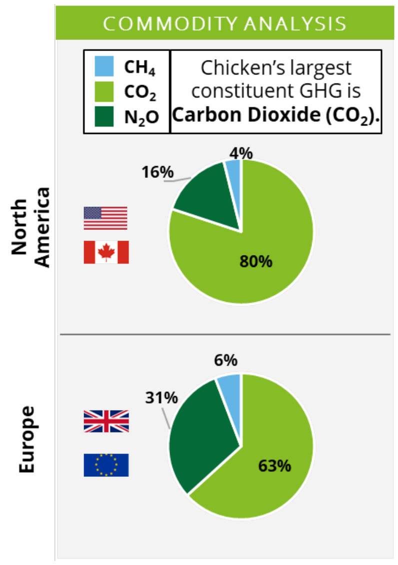


Figure 14: Poultry SBTi FLAG Results

SBTi FLAG Results

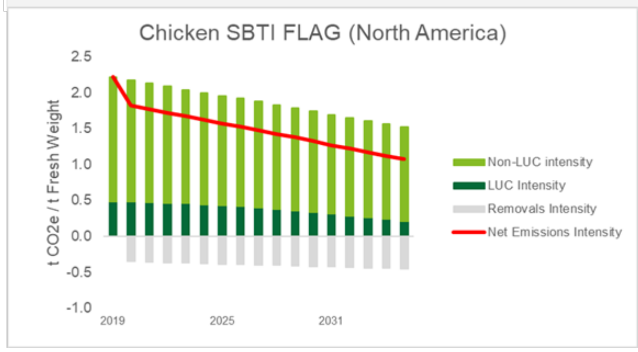
Emissions intensity units: t CO_2e / t Fresh Weight

North America

	Net Emissions Target		Non-LUC Emissions		LUC Emissions	Removals
	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	t CO_2e / t Fresh Weight
2019	2.22		1.73		0.49	0.00
2030	1.32	-40%	1.41	-19%	0.34	-0.42
2035	1.07	-52%	1.31	-24%	0.21	-0.45

Europe

	Net Emissions Target		Non-LUC Emissions		LUC Emissions	Removals
	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	t CO_2e / t Fresh Weight
2019	5.03		2.51		2.52	0.00
2030	3.03	-40%	1.74	-31%	1.74	-0.45
2035	2.13	-58%	1.51	-40%	1.10	-0.49



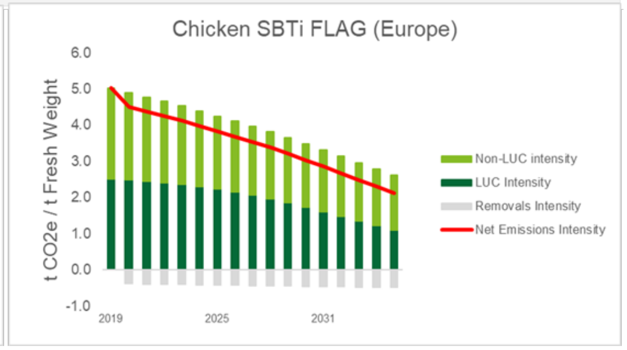


Figure 14 shows that for poultry, achieving the FLAG target for net emissions intensity by 2035 will require a 52% reduction of total emissions compared to the 2019 baseline for North America, and a 58% reduction compared to the 2019 baseline for Europe. The charts illustrate the estimated reduction over time, with the red "Net Emissions Intensity" line showing the target, the light green bars showing the reduction in non-land use change emissions intensity, and the dark green bars showing land use change emissions intensity. The gray bars below the chart represent the removals required for the FLAG targets for poultry, inclusive of in-supply chain activities.

Achieving the targets outlined in Figure 14 will require addressing and prioritizing by greenhouse gas and emissions driver. For North American and European FLAG companies with poultry in their value chains, **carbon dioxide plays a critical role to achieving their commodity intensity targets. Reductions from the primary emissions driver, feed production, are likely to make up 10-15% of required annual intensity reductions by 2035**, **based on the average baseline emissions, required rate of reduction from SBTi FLAG targets, and an LCA meta-analysis of abatement opportunities.**

BY-GAS ABATEMENT OPPORTUNITIES

Table 5 below summarizes the breakdown of greenhouses gases and primary drivers of emissions for chicken, as well as steps companies can take to reduce those emissions through a gas-specific approach. It is important to note that while CO_2 represents the largest constituent gas for poultry, nitrous oxide also contributes significantly.

Table 5: Chicken Abatement Opportunities

Greenhouse Gas	Primary Emissions Driver	North America		Europe		Recommended Abatement Actions		
		% emissions from Gas	% total emissions	% emissions from Gas	% total emissions	ACT *Implement & scale today*	ADVOCATE *Set the foundation for tomorrow*	ADVANCE *Innovate to close the gap long-term*
Carbon Dioxide	Direct Energy Use	22%	18%	23%	14%	**Poultry House Management** Implement educational programs for best management practice in poultry houses for energy efficiency and ventilation Install behind-the-meter solar on poultry house sites, as well as other design/retrofit solutions to reduce energy intensity	**Renewable Energy** Lobby for increased access to renewable energy across regions	**Poultry House Management** Innovate to develop new design/retrofit solutions to reduce energy intensity **Renewable Energy** Support and invest in advancements in renewable energy technologies
	Feed	76%	72%	74%	75%	**Feed Management** Use precision feeding and monitoring technologies to optimize feeding time, amount, and nutrition	**Feed Management** Support creation of more regulated parameters for alternative feed sources like insects on treatment for safe consumption	**Feed Management** Identify and explore pilot and partnership opportunities on alternative feed innovation, such as with reputable insect protein suppliers
Nitrous Oxide	Feed	69%		83%				
Methane	Manure Management	69%	9%	84%	8%	**Poultry House Management** Implement educational programs for best management practices in poultry houses for manure management & litter maintenance	**Fertilizer Solutions** Support development and use of standard guidance on determining poultry litter application rates based on nutrient testing in crop soil	**Fertilizer Solutions** Support efforts to scale composting / processing of manure for reuse as fertilizer

Note: The "percent emissions from gas" columns highlight what percentage of all of the emissions from the row's specific constituent gas this primary emissions driver makes up, for North America and Europe each in their respective columns. The "percent total emissions" columns demonstrate what percentage that particular emissions driver makes up of the commodity's total emissions, for North America and Europe each in their respective columns

Feed

In addition to reducing emissions in corn and soy production (explored later in this report), chicken feed emissions can be made less intensive by supplementing diets, such as with protease, an enzyme demonstrating widely researched improvements to protein utilization, reducing need for soy supplementation as well as reducing nitrogen excretion in manure.[26] Insect protein presents one promising feed alternatives to soy in terms of emissions intensity reduction and is commercially available today. Studies have yielded enhanced growth performances in chicken fed insect protein compared to soybean meal, with no significant differences in digestibility.[27] Companies can explore piloting the use of insect protein for chicken feed, at the same time advocating and funding further development of specific parameters to guarantee safe and thorough treatment of insects to eliminate pathogens and other health concerns.

Climate-Smart Commodities

Tyson Foods is leading a $152M effort to accelerate the adoption of climate-smart practices, $61M of which has been funded under USDA's Climate Smart Commodities program. Approximately 75% of the USDA grant will go directly towards incentive payments and technical assistance to farmers adopting climate-smart practices, with the remaining 25% supporting program measurement, monitoring, reporting, and validating. Over the course of the five-year program, Tyson projects a reduction of 1.9 million metric tons of GHG emissions and an increase of climate-smart agricultural practices (e.g., chicken feed production practices) across six million acres. "Equally important," the food production company estimates, the effort will "put nearly $100 million back into the pockets of farmers and ranchers within Tyson's value chain."

McDonald's is one of the many partners engaged in this initiative supporting a future of sustainable agriculture practices across the U.S.

Poultry house management

Chicken manure is often managed in enclosed poultry houses with litter (a mixture of wood shavings, straw, and sawdust to absorb moisture). Ammonia inherent in poultry manure can elevate health risks to chickens and nearby communities and contribute to downwind soil acidification and water quality impairment and must be managed with regulation of litter moisture (e.g., through fans or natural ventilation) and additions of poultry litter treatments to reduce ammonia emissions[28]

To reduce CO_2 emissions and energy costs caused by inefficient energy management of large poultry houses, the buildings can undergo energy efficiency retrofits with the addition of on-site solar panels (i.e., solar photovoltaics).

Fertilizer

Poultry litter contains valuable nutrients like nitrogen that can be used as a fertilizer, reducing even more poultry emissions if the fertilizer is applied within the supply chain to chicken feed crops. Incorporating fertilizer from poultry manure within the feed crop supply chain of those poultry would reduce the need for synthetic fertilizer production, which would reduce the upstream emissions inherent in fertilizer production. Composting poultry litter can stabilize nutrients, reduce odors, and improve quality of litter as a soil conditioner. In order to exercise proper application of poultry litter, its nutrient content must be tested against specific crop nutrient requirements based on soil test data. A litter application rate, as well as supplemental nutrients needed for optimum crop growth, must also be understood.

NOTABLE CONSIDERATIONS

Before implementing large-scale automation or other operational efficiencies in poultry houses, it is important to understand the additional energy demand required by smart machinery, as new equipment run on fossil fuels may outweigh the operational efficiencies they enable.

[26] Leinonen, I. and Kyriazakis, I. (2016, March 3). *Cambridge University Press.* How can we improve the environmental sustainability of poultry production?

[27] Slimen, I. Et. al. (2023, August). *Vet. Sci.* Insects as an alternative protein source for poultry nutrition: a review. https://doi.org/10.3389/fvets.2023.1200031

[28] Chai, L. and Ritz, C. (2022, December). *Journal of the NACAA.* Litter acidification for controlling ammonia levels in poultry houses – a review.. https://www.nacaa.com/file.ashx?id=9f14dd1a-7d5c-4b0e-9884-847d65b29d49

CROP COMMODITIES

Overview

Current row crop agricultural practice generates about 5% of GHG emissions in the U.S. and EU, but it is estimated that a 71% reduction of these row-crop emissions can be achieved within the next 15 years (since the study's publication in 2021).[29]

Climate-smart practices

Climate-smart agriculture encompasses a set of practices for managing croplands and other landscapes to reduce food and land use change emissions and restore degraded land while optimizing productivity. Beyond traditional rotations, climate-smart agriculture employs diversified crop systems and practices such as agroforestry (cultivating trees within crop systems), reduced tillage (minimizing disturbance of soil) and perennial crops (year-round plants that absorb excess cash crop nutrients) to improve soil health and ecological diversity.[30]

In May 2023, the U.S. introduced the **Conservation Opportunity and Voluntary Environmental Resilience Program (COVER) Act,** which incentivizes the use of cover crops to improve soil health and reduce the risk of crop failures caused by flooding and drought. The COVER Act will offer a $5 / acre discount for crop insurance premiums for producers who utilizer cover crop systems, as well as technical assistance in developing a soil health pilot program to investigate soil health practices. The appropriateness of cover crops to different regions and systems should be considered prior to implementation.

Soil health

Soil health presents a critical determinant to reaching FLAG targets; when neglected, soil erosion proves costly and even disastrous (the Dust Bowl in the U.S. Great Plains was caused in part by widespread soil erosion). When nurtured, soil has the possibility of sequestering carbon and maintaining existing carbon stores while improving crop yield and resilience. Tried and true soil health practices include:

- Utilizing buffer and prairie strips and sediment control basins to prevent nutrient runoff
- Protecting otherwise bare soil with cover crops to absorb excess nutrients and prevent erosion
- Integrating livestock where feasible to promote nutrient cycling and add microbes through grazing with appropriate stocking rates Countless case studies on climate-smart agriculture have proven its practices to reduce emissions. However, adopting climate-smart agriculture requires massive transformation from the status quo, and often a shift to more complex management that requires significant financial and technical assistance in order to stick. The U.S. and EU have increased acknowledgement of climate-smart agriculture through handsome public incentives and other forms of payment in recent years; for example, the EU has allocated at least 25% of its 2023-2027 Common Agricultural Policy (CAP) budget for direct payments to "eco-schemes" rewarding climate-friendly farming practices. FLAG companies must liaise over grower adoption of such incentives to scale climate-smart agriculture at the volume needed to reach emissions reduction targets while often needing to assure continuous improvement of the environmental outcomes and co-benefits to the landscape. Early adopters of climate-smart practices often face tension due to current requirements for companies to show change on average year-over-year. Outlined below are some critical ways companies can offer technical and financial support to producers in their value chains in practice adoption.

[29] Northrup, D. Et. al. (2021, June 21). *PNAS.* Novel technologies for emissions reduction complement conservation agriculture to achieve negative emissions form row-crop production. https://doi.org/10.1073/pnas.2022666118

[30] Smith, M. Et. al. (2023, March 3). *Communications Earth & Environment,* Increasing crop rotational diversity can enhance cereal yields. https://www.nature.com/articles/s43247-023-00746-0

Reduced fuel and energy use

Analysis of the crop commodities covered in this report revealed common primary emissions drivers around the production and usage of fuel for machinery and fertilizer. Fuels like diesel and natural gas for farm machinery are considered a direct source of farm energy consumption and can be generally reduced by shifts to low- or no-tillage practices requiring less intensive machine operation.

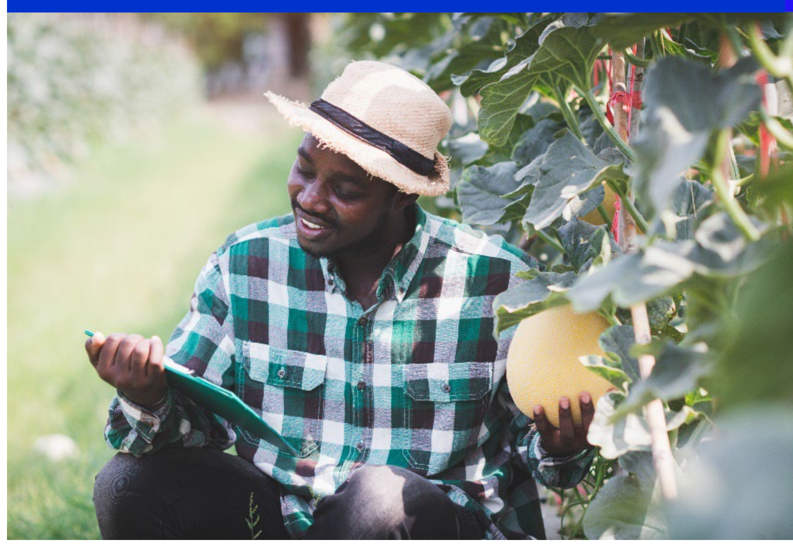
Beyond this, FLAG companies must record emissions in the production of ammonia for fertilizer as an indirect source of energy consumption. Fertilizer production is extremely emissions intensive, with the century-old Haber-Bosch process for making ammonia producing nearly 2 tons of CO_2 for every ton of usable product.[31] Excessive fertilizer usage is doubly consequential through the N_2O emissions released from fertilized soil into the atmosphere.

Innovations have emerged to address the weight of fertilizer application and production emissions. Digital agriculture and agronomic modeling technically enable enhanced forecasting and more precise fertilizer application aligned to the "5R guidance": right inputs, right rate, right time, right place, and right way. Bio-based fertilizers consisting of microbially derived nitrogen reduce the need for chemical inputs, and farms managing both livestock and crops can substitute composted manure for fertilizer in a shift to a more circular model. Creative variations of green ammonia solutions using lower-carbon energy sources (including green hydrogen, biogas produced by existing sources of methane leakage such as manure) for the Haber-Bosch process are being developed to meet agriculture (as well as maritime) demand in line with emissions reduction targets. Such solutions require significantly more investment and attention to scale while maintaining careful oversight, given ammonia's highly toxic and corrosive chemical nature and leakage risks associated with storage of hydrogen as a feedstock.[32]

Appealing to Growers

Recognizing the need to work hand-in-hand with farmers to execute agriculture programs aimed at revitalizing the ground, Bayer launched ForGround: a platform geared towards the advancement of supply chain practices supporting soil health, reducing erosion, and increasing soil water availability. Offering a free subscription to its Climate FieldView Platform, ForGround enables farmers to access evidence-based agronomic resources, financial incentives tied to climate-smart practices, and discounts on associated practice costs such as conservation tillage equipment and cover crops. In return, Bayer can more easily collect farmer field data through the digital farming tool.

Since its launch in August 2022, farmers have enrolled millions of acres in ForGround to access its benefits. "Last fall I ended up winning their LaCrosse Seed sweepstakes," said Brayn Stancyzk, a corn and soybean farmer in Nebraska. "I look forward to expanding cover crops in my operations with [this] support."



[31] *Science News* (2021, June). World-first discovery could fuel the new green ammonia economy. https://www.sciencedaily.com/releases/2021/06/210610150110.htm

[32] Jones, N., *Yale Environment 360* (2022, January 20). From Fertilizer to Fuel: Can 'Green' Ammonia Be a Climate Fix? https://e360.yale.edu/features/from-fertilizer-to-fuel-can-green-ammonia-be-a-climate-fix

Practice change needs support to take root

MANAGEMENT

Local teams of agronomists can help advise farmers on the implications of new practices and how different crops will affect their overall business

ADAPTATION

Climate-smart practices will often require the retrofitting or purchase of new farm equipment. These funding needs should not be solely placed on the farmer

COMPENSATION

Innovative financing and programs are needed to behaviorally incentivize practice changes and dis-incentivize deforestation, while assuring profitability for growers

NOTABLE CONSIDERATIONS

Biochar, a soil amendment produced through pyrolysis (the generation of energy from biomass in the absence of oxygen), has emerged as a removal solution that can hold carbon within the soil and may improve soil physical properties. There are still many unknowns with the use of biochar, including on scalability and impact, the potential for biochar production to compete with bioenergy production where bioenergy production could have been used as a substitute for fossil fuels, and ensuring that purpose-grown biomass for biochar production won't cause land conversion.

COMMODITY DEEP DIVE: CORN

Overview

Corn's use as a primary feed source for livestock and high yields have contributed to its widespread abundance as a crop, especially in North America.

Corn emissions in context of SBTi FLAG targets

To contextualize for SBTi FLAG, companies working toward a corn commodity target would need to see reductions following the trajectory outlined in Figure 16 below.

Figure 15: Corn Commodity Analysis

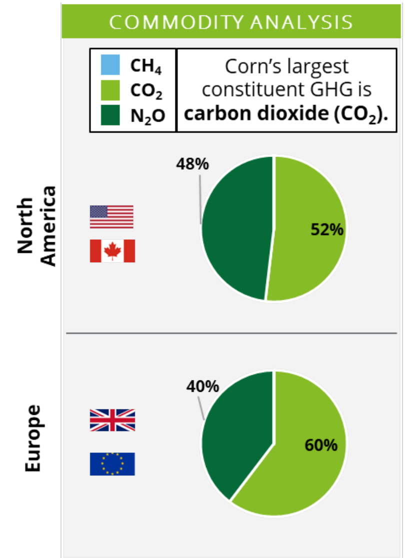


Figure 16: Corn SBTi FLAG Results

SBTi FLAG Results

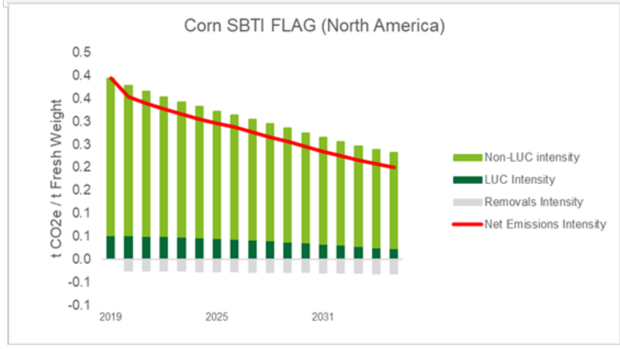
Emissions intensity units: t CO_2e / t Fresh Weight

North America

	Net Emissions Target		Non-LUC Emissions		LUC Emissions	Removals
	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	t CO_2e / t Fresh Weight
2019	0.39		0.34		0.05	0.00
2030	0.25	-38%	0.24	-30%	0.04	-0.03
2035	0.20	-49%	0.21	-39%	0.02	-0.03

Europe

	Net Emissions Target		Non-LUC Emissions		LUC Emissions	Removals
	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	t CO_2e / t Fresh Weight
2019	0.42		0.34		0.08	0.00
2030	0.27	-35%	0.25	-26%	0.05	-0.03
2035	0.22	-46%	0.23	-33%	0.03	-0.04



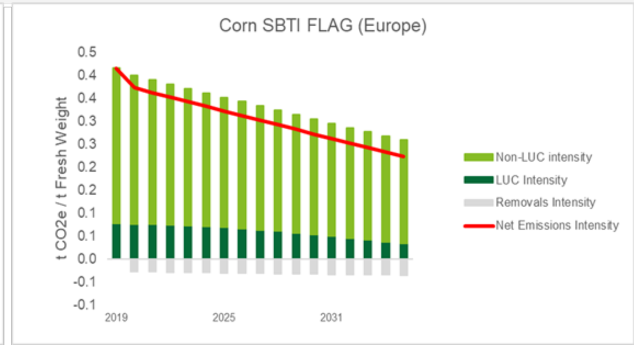


Figure 16 indicates that for corn, achieving the FLAG target for net emissions intensity by 2035 will require a 49% reduction of total emissions compared to the 2019 baseline for North America. For Europe, a reduction of 46% compared to the 2019 baseline will be required. The charts show the estimated reduction over time, with the red "Net Emissions Intensity" line showing the target, the light green bars showing the reduction in non-land use change emissions intensity, and the dark green bars showing land use change emissions intensity. The gray bars below the chart represent the removals required for the FLAG targets for corn, inclusive of in-supply chain activities. Achieving the targets outlined in Figure 16 will require addressing and prioritizing by greenhouse gas and emissions driver. For North American and European FLAG companies with corn in their value chains, both carbon dioxide and nitrous oxide play a critical role to achieving their commodity intensity targets. Carbon dioxide is the largest constituent gas, with multiple emissions drivers contributing to the total for that gas (e.g., machinery and fuel use, other field inputs). **Reductions of carbon dioxide from the second largest emissions driver overall, machinery and fuel use, are likely to make up 10-15% of required annual intensity reductions by 2035**, **based on the average baseline emissions, required rate of reduction from SBTi FLAG targets, and an LCA meta-analysis of abatement opportunities.** However, it is also worth noting that the largest single driver of emissions is field emissions, which release nitrous oxide. **Reductions from the primary emissions driver, field emissions, are likely to make up 35-40% of required annual intensity reductions by 2035**.

BY-GAS ABATEMENT OPPORTUNITIES

Table 6 below summarizes the breakdown of greenhouses gases and primary drivers of emissions for corn, as well as steps companies can take to reduce those emissions through a gas-specific approach.

Table 6: Corn Abatement Opportunities

Greenhouse Gas	Primary Emissions Driver	North America		Europe		Recommended Abatement Actions		
		% emissions from Gas	% total emissions	% emissions from Gas	% total emissions	ACT *Implement & scale today*	ADVOCATE *Set the foundation for tomorrow*	ADVANCE *Innovate to close the gap long-term*
Nitrous Oxide	Field Emissions	100%	48%	100%	40%	**Nutrient Management** Scale customizable, variable-rate technologies for more precise nitrogen application **Intercropping** Intercrop corn with small grains and legumes to reduce need for chemical inputs **Climate-Smart Practices** Conduct site assessments to create customized climate-smart plans for farms Subsidize new purchases or retrofits of existing equipment **Soil Health** Implement windbreaks, riparian buffers, and other practices aimed at reducing soil erosion	**Nutrient Management** Promote educational programs and outreach initiatives on nitrogen management practices **Intercropping** Promote education on the integration of non-crop plants (e.g. cover crops) for soil health **Soil Health** Increase grower enrollment in cover cropping technical and financial assistance Support public incentives for practices that improve soil health, such as cover cropping **Climate-Smart Practices** Allocate land and operations for "research farms" piloting sustainable practices	**Genetics** Support research and development on improved genetics
Carbon Dioxide	Machinery, Equipment & Fuel Use	58%	30%	59%	34%	**Renewable Energy** Deploy renewable energy technologies (e.g., farm equipment) as possible	**Renewable Energy** Pilot emerging technologies (e.g., sensors, IoT) to limit fuel and energy use in production	**Fertilizer Research** Support research of fertilizers produced using renewables

Note: The "percent emissions from gas" columns highlight what percentage of all of the emissions from the row's specific constituent gas this primary emissions driver makes up, for North America and Europe each in their respective columns. The "percent total emissions" columns demonstrate what percentage that particular emissions driver makes up of the commodity's total emissions, for North America and Europe each in their respective columns

Additional considerations on key recommendations with a focus on corn are detailed below.

Nitrogen management

While corn's high levels of crop residue (waste materials such as stalks) can enrich soil, it also requires relatively high levels of nitrogen, making nitrogen management techniques such as precision application particularly important for reducing nitrous oxide emissions in this crop. EDF's nitrogen balance tool is a user-friendly, scientifically robust way to assess environmental results.[33]

Renewable energy

Corn also requires energy for grain drying following harvest, which is done with high temperature dryers or electric fan dryers. A continuous cross-flow grain dryer is the most commonly used in Canada today, but can waste as much as 40% of the energy it uses.[34] Switching to an electric fan dryer reduces heat usage and can improve dryer energy use by up to 30%, and practices such as transferring grain from dryer to a bin to cool have also been shown to yield significant fuel and energy savings.[25]

Genetics

Corn's increased yields can be credited to the crop's responsiveness to genetic modifications. Sources have touted improvements in crop genetics as a crucial lever for limiting land conversion and associated emissions, estimating that global land use for cereal production would have expanded over 6 times more than it did thanks to the yield improvements enabled by selective breeding.[35] In addition to improving yield efficiency, genetics can be used as a lever for nitrogen balance. In researching genetics, it is essential to assess health, environmental, social, and economic risks and benefits, which often vary by organism, geography, and across other variables.

NOTABLE CONSIDERATIONS

Corn is a high residue crop, meaning it leaves a lot of plant material (e.g. corn stalks) following a harvest or severe weather. In instances of heavy crop residue, mechanical processes additional to a standard combine pass are needed to prepare the soil for productivity and cover cropping the following season. Low-aggression vertical tillage tolls have been shown to process corn residue effectively with minimal soil disturbance.

[33] Environmental Defense Fund (2022, February). *Making invisible loss of nitrogen visible.* https://www.edf.org/ecosystems/making-invisible-loss-nitrogen-visible-farm-and-future

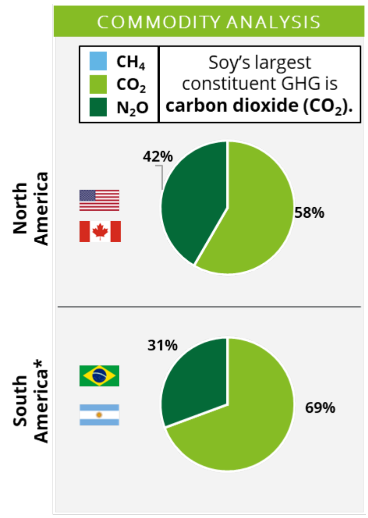
[34] Dyck, J. and Eng. P. (2017, January). *Ministry of Agriculture, Food and Rural Affairs.* Reducing Energy Use in Grain Dryers. https://files.ontario.ca/omafra-reducing-energy-use-in-grain-dryers-17-001-en-2023-06-29.pdf

[35] Our World in Data based on the Food and Agriculture Organization of the United Nations. https://ourworldindata.org/grapher/cereal-land-spared

Overview

Almost 80% of the world's soybean crop is fed to livestock, extending the importance of reducing emissions in this crop to other commodity targets.[36] Progress has been made in the past few decades to reduce soy emissions associated with energy use due to the spread of no-till and conservation tillage practices.[37] However, challenges with field emissions remain—despite the fact that soy can fix nitrogen from the atmosphere, an initial nitrogen fertilizer application and often supplemental nitrogen fertilizers are needed to reach yield potentials.[38]

Figure 17: Soy Commodity



Soy emissions in context of SBTi FLAG targets

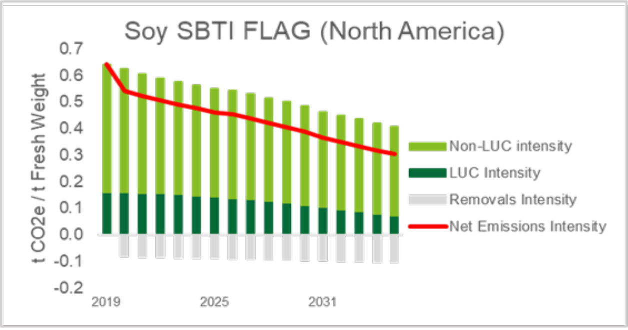
For this report, South America was used as regional substitute for Europe due to the availability of LCA data. This region was selected as a proxy because soy from South America makes up a high proportion of all soy imports to Europe. Within the SBTi Tool, the analysis used Brazil specifically for calculating targets.

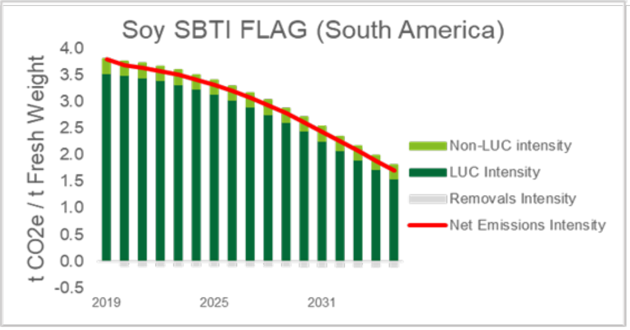
Figure 18: Soy SBTi FLAG Results

SBTi FLAG Results

Emissions intensity units: t CO_2e / t Fresh Weight

Region	Year	Net Emissions Target		Non-LUC Emissions		LUC Emissions	Removals
		t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	t CO_2e / t Fresh Weight
North America	2019	0.64		0.48		0.16	0.00
	2030	0.39	-40%	0.37	-22%	0.11	-0.10
	2035	0.30	-53%	0.34	-30%	0.07	-0.10
South America	2019	3.80		0.26		3.54	0.00
	2030	2.61	-31%	0.26	0%	2.45	-0.10
	2035	1.71	-55%	0.26	0%	1.55	-0.10





[36] *World Wildlife Fund,* Soy. https://wwf.panda.org/discover/our_focus/food_practice/sustainable_production/soy/#:~:text=In%20fact%2C%20almost%2080%25%20of,butter%2C%20yogurt%2C%20etc).

[37] *Field to Market,* Greenhouse Gas Emissions. https://fieldtomarket.org/national-indicators-report/greenhouse-gas-emissions/

[38] Schmidt, J. (n.d.). *Pioneer.* Nitrogen fertilizer for soybean? https://www.pioneer.com/us/agronomy/nitrogen_fertilizer_soybean.html

In the context of SBTi FLAG, companies working toward a soy commodity target would need to see reductions in line with Figure 18. Achieving the target for net emissions intensity by 2035 will require a 53% reduction of total emissions compared to the 2019 baseline for North America. For South America, a reduction of 55% compared to the 2019 baseline will be required. The charts show the estimated reduction over time, with the red "Net Emissions Intensity" line showing the target, the light green bars showing the reduction in non-land use change emissions intensity, and the dark green bars showing land use change emissions intensity. The gray bars below the chart represent the removals required, inclusive of in-supply chain activities. As shown, land use change intensity is particularly significant for the FLAG target for soy in South America.

Achieving the targets outlined in Figure 18 will require addressing and prioritizing by greenhouse gas and emissions driver. For North and South American FLAG companies with soy in their value chains, both carbon dioxide and nitrous oxide a critical role to achieving their commodity intensity targets.

Carbon dioxide is the largest constituent gas, with multiple emissions drivers contributing to the total for that gas (e.g., machinery and fuel use, other field inputs). **Reductions of carbon dioxide from the second largest emissions driver overall, machinery and fuel use, are likely to make up 1-5% of required annual intensity reductions by 2035**, **based on the average baseline emissions, required rate of reduction from SBTi FLAG targets, and an LCA meta-analysis of abatement opportunities.** The largest single driver of emissions is field emissions, which release nitrous oxide. **Reductions from the primary emissions driver, field emissions, are likely to make up 15-20% of required annual intensity reductions by 2035**. It is also worth noting that for South America, estimated reductions from non-land use change emissions are 0% because of the outsize climate impacts of land use change in this region. Managing for the significant, associated land use change impacts of soy is critical; however, there are opportunities for non-land use change emissions reductions.

BY-GAS ABATEMENT OPPORTUNITIES

Table 7 below summarizes the breakdown of greenhouses gases and primary drivers of emissions for soy, as well as steps companies can take to reduce those emissions through a gas-specific approach.

Table 7: Soy Abatement Opportunities

Greenhouse Gas	Primary Emissions Driver	North America		South America		Recommended Abatement Actions		
		% emissions from Gas	% total emissions	% emissions from Gas	% total emissions	ACT *Implement & scale today*	ADVOCATE *Set the foundation for tomorrow*	ADVANCE *Innovate to close the gap long-term*
Nitrous Oxide	**Field Emissions**	100%	42%	100%	31%	**Nutrient Management** Scale customizable, variable-rate technologies for more precise nitrogen application **Intercropping** Intercrop soy with small grains and legumes to reduce need for chemical inputs **Climate-Smart Practices** Conduct site assessments to create customized climate-smart plans for farms Subsidize new purchases or retrofits of existing equipment **Soil Health** Implement windbreaks, riparian buffers, and other practices aimed at reducing soil erosion	**Nutrient Management** Promote educational programs and outreach initiatives on nitrogen management practices **Intercropping** Promote education on the integration of non-crop plants (e.g. cover crops) for soil health **Soil Health** Increase grower enrollment in cover cropping technical and financial assistance Support public incentives for practices that improve soil health, such as cover cropping **Climate-Smart Practices** Allocate land and operations for "research farms" piloting sustainable practices	**Genetics** Support research and development on improved genetics **Nitrogen Fixing** Support research on compatible microbes and conduct tests
Carbon Dioxide	**Machinery, Equipment & Fuel Use**	41%	25%	42%	29%	**Renewable Energy** Deploy renewable energy technologies (e.g., farm equipment) as possible	**Renewable Energy** Pilot emerging technologies (e.g., sensors, IoT) to limit fuel and energy use in production	**Fertilizer Research** Support research of fertilizers produced using renewables

Note: The "percent emissions from gas" columns highlight what percentage of all of the emissions from the row's specific constituent gas this primary emissions driver makes up, for North America and Europe each in their respective columns. The "percent total emissions" columns demonstrate what percentage that particular emissions driver makes up of the commodity's total emissions, for North America and Europe each in their respective columns

Additional considerations on key recommendations with a focus on soy are detailed below.

Intercropping

The practice of integrating alternative crops or non-crop plants with cash crops, known as intercropping, has deep historical roots. However, intercropping remains limited to smaller farm operations as intensified soy production tends to maximize soy inputs across land rather than accommodate non-commodity crops. Commercial soy production misses out on the many benefits of intercropping, including improved soil health, increased resilience, reduced nutrient runoff and thus reduced field emissions. Intercropping is particularly advantageous with soy because of its natural nitrogen fixation properties that can add to other nitrogen-fixing legumes used in cover crops, further enhancing nitrogen availability in the soil for commodity crops, thus reducing the need for synthetic nitrogen fertilizers. Further, intercropping with non-nitrogen-fixing cover crops beyond soybean harvests could also reduce nitrogen losses, and reduce the need for fertilizer for the following crop by keeping nitrogen in the system.

"Almost 80% of the world's soybean crop is fed to livestock, extending the importance of reducing emissions in this crop to other commodity targets."

NITROGEN FIXING

Soy's biological nitrogen fixation properties (i.e., symbiosis with microorganisms that naturally create ammonia as a nutrient) can be maximized to reduce the needed nitrogen from fertilizer. Achieving full potential of biological nitrogen fixation, such as pairing soy with the rhizobia bacteria, requires further attention to understand the specific pairings of strains needed to maximize nitrogen efficiency. In tandem with funding further biological fixation studies, FLAG companies can conduct soil tests to more precisely understand soy's nitrogen requirements and pilot various enhanced efficiency fertilizers (EEFs) on the market formulated to control fertilizer release to lower overall nitrogen application rates.

NOTABLE CONSIDERATIONS

Soy is the second-largest driver of deforestation after beef, as it can only produce one yield per cycle and thus requires more intensive land-use. Companies may thus need to tie deforestation commitments with soy purchasing agreements.

COMMODITY DEEP DIVE: WHEAT

Overview

As a high-yielding cereal crop, wheat demands relatively large amounts of nutrients, including nitrogen, throughout its critical growth stages.

Wheat emissions in context of SBTi FLAG targets

To consider wheat in the context of SBTi FLAG, companies working toward target for this commodity would need to see reductions following the trajectory outlined in the table and charts below.

Figure 19: Wheat Commodity Analysis

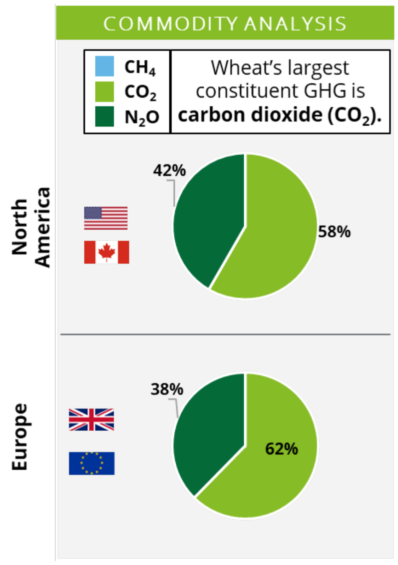


Figure 20: Wheat SBTi FLAG Results

SBTi FLAG Results

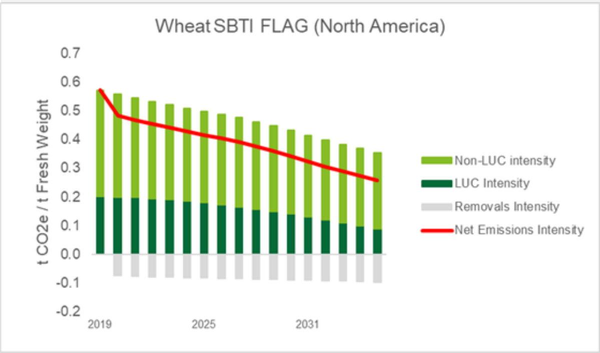
Emissions intensity units: t CO_2e / t Fresh Weight

North America

	Net Emissions Target		Non-LUC Emissions		LUC Emissions	Removals
	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	t CO_2e / t Fresh Weight
2019	0.57		0.37		0.20	0.00
2030	0.34	-40%	0.29	-21%	0.14	-0.09
2035	0.26	-55%	0.27	-28%	0.09	-0.10

Europe

	Net Emissions Target		Non-LUC Emissions		LUC Emissions	Removals
	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	% reduction from baseline	t CO_2e / t Fresh Weight	t CO_2e / t Fresh Weight
2019	0.44		0.35		0.08	0.00
2030	0.29	-34%	0.28	-22%	0.06	-0.05
2035	0.24	-45%	0.25	-28%	0.04	-0.05



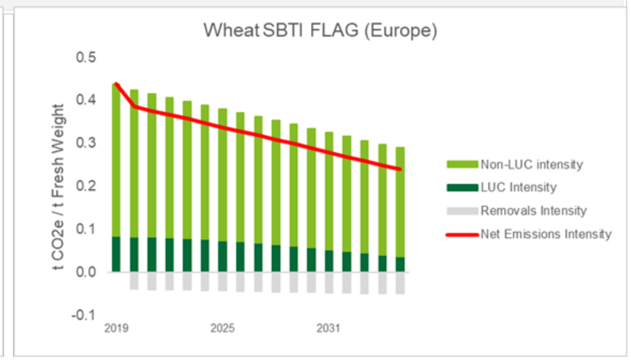


Figure 20 demonstrates that achieving the FLAG target for net emissions intensity by 2035 for wheat will require a 55% reduction of total emissions compared to the 2019 baseline for North America, and a reduction of 45% compared to the 2019 baseline for Europe. The charts show the estimated reduction over time, with the red “Net Emissions Intensity” line showing the target, the light green bars showing the reduction in non-land use change emissions intensity, and the dark green bars showing land use change emissions intensity. The gray bars below the chart represent the removals required for the FLAG target for wheat, inclusive of in-supply chain activities. Achieving the targets for wheat outlined in Figure 20 will require addressing and prioritizing by greenhouse gas and emissions driver. For North American and European FLAG companies with wheat in their value chains, both carbon dioxide and nitrous oxide play a critical role to achieving their commodity intensity targets. Carbon dioxide is the largest constituent gas, with multiple emissions drivers contributing to the total for that gas (e.g., fertilizer production, machinery and fuel use, other field inputs). **Reductions of carbon dioxide from the second largest emissions driver overall, fertilizer production, are likely to make up 10-15% of required annual intensity reductions by 2035**, **based on the average baseline emissions, required rate of reduction from SBTi FLAG targets, and an LCA meta-analysis of abatement opportunities.** However as with the other crop commodities, the largest single driver of emissions is field emissions, which release nitrous oxide. **Reductions from the primary emissions driver, field emissions, are likely to make up 20-25% of required annual intensity reductions by 2035**.

BY-GAS ABATEMENT OPPORTUNITIES

Table 8 below summarizes the breakdown of greenhouses gases and primary drivers of emissions for wheat, as well as steps companies can take to reduce those emissions through a gas-specific approach.

Table 8: Wheat Abatement Opportunities

Greenhouse Gas	Primary Emissions Driver	North America		Europe		Recommended Abatement Actions		
		% emissions from Gas	% total emissions	% emissions from Gas	% total emissions	ACT *Implement & scale today*	ADVOCATE *Set the foundation for tomorrow*	ADVANCE *Innovate to close the gap long-term*
Nitrous Oxide	**Field Emissions**	100%	42%	100%	38%	**Nutrient Management** Implement site-specific nutrient management plans with regular soil testing Scale use of precision fertilizer application technologies **Intercropping** Intercrop wheat with small grains and legumes to reduce need for chemical inputs **Climate-Smart Practices** Conduct site assessments to create customized climate-smart plans for farms Subsidize new purchases or retrofits of existing equipment **Soil Health** Implement windbreaks, riparian buffers, and other practices aimed at reducing soil erosion	**Nutrient Management** Create private-public partnerships (PPPs) to fund and build internet infrastructure across rural areas **Intercropping** Promote education on the integration of non-crop plants (e.g. cover crops) for soil health **Soil Health** Increase grower enrollment in cover cropping technical and financial assistance Support public incentives for practices that improve soil health, such as cover cropping **Climate-Smart Practices** Allocate land and operations for “research farms” piloting sustainable practices	**Genetics** Support research and development on improved genetics
Carbon Dioxide	**Fertilizer Production**	64%	36%	54%	30%	**Renewable Energy** Deploy renewable energy technologies to power production as possible	**Renewable Energy** Pilot emerging technologies (e.g., sensors, IoT) to limit fertilizer use in production	**Fertilizer Research** Support research of fertilizers produced using renewables

Note: The “percent emissions from gas” columns highlight what percentage of all of the emissions from the row’s specific constituent gas this primary emissions driver makes up, for North America and Europe each in their respective columns. The “percent total emissions” columns demonstrate what percentage that particular emissions driver makes up of the commodity’s total emissions, for North America and Europe each in their respective columns

Finally, additional considerations on key recommendations with a focus on wheat are detailed below.

Nutrient management

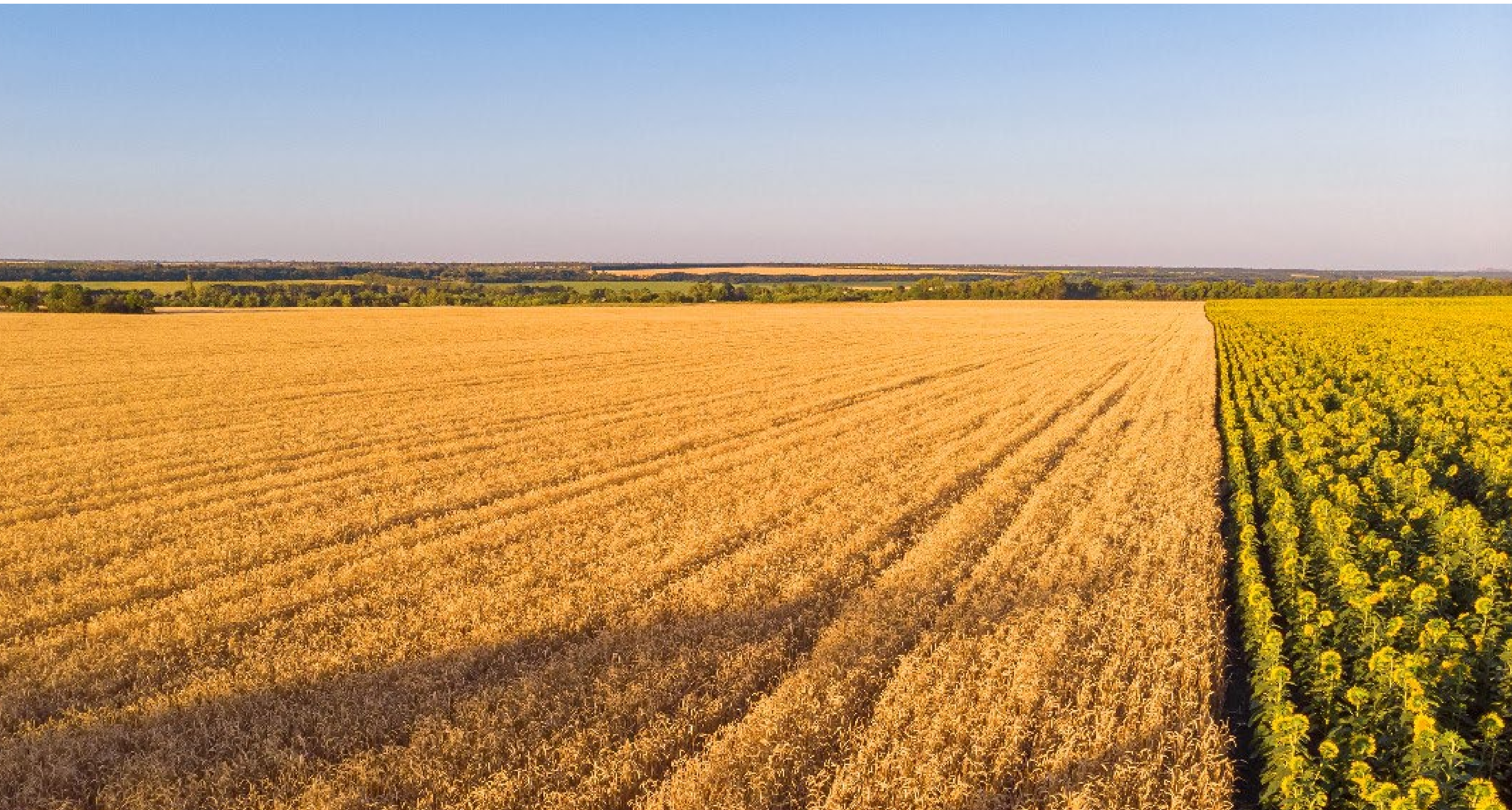
Wheat's prevalence as a staple crop has led to many different varieties with different planting times and growth habits. Solutions for this crop must thus acknowledge the specificity required to effectively address the nuances of wheat varieties. Variable Rate Technologies (VRTs) fit well for this need, as they use sensing systems and computer programs for precise application (i.e., different rates across the same field) of agrochemicals. Site-specific nutrient management tools have been shown to increase wheat crop yields while reducing emissions intensity but can be challenging for farmers to adopt without dedicated technical and up-front financial assistance to decrease time to achieve return on investment.

Genetics

Wheat has lacked attention to genetics relative to other crops and therefore warrants a particular focus on extensive field testing to record genotype and phenotype data. Recently developed field-deployable instruments allow direct monitoring of root system architecture, presenting the potential to unlock a volume of information that can be used to select and scale wheat trait packages optimized for nutrient extraction and resilience. In researching genetics, it is essential to assess health, environmental, social, and economic risks and benefits, which often vary by organism, geography, and across other variables.

NOTABLE CONSIDERATIONS

Adoption of precision technologies optimizing for nutrient management, as well as genetically-modified crop seeds, must be heavily subsidized by governments and downstream FLAG companies to stimulate widescale adoption by smallholders. While most digitization and monitoring technologies are mature, most rely on continuous internet coverage that not all growers may be able to access.



CONCLUSION

Prioritization of Emissions Reduction

Taken together, the recommendations specific to each commodity identify the actions with the best potential when adopted at scale to achieve sector-wide emissions reduction in alignment with the SBTi FLAG target based upon currently available science.

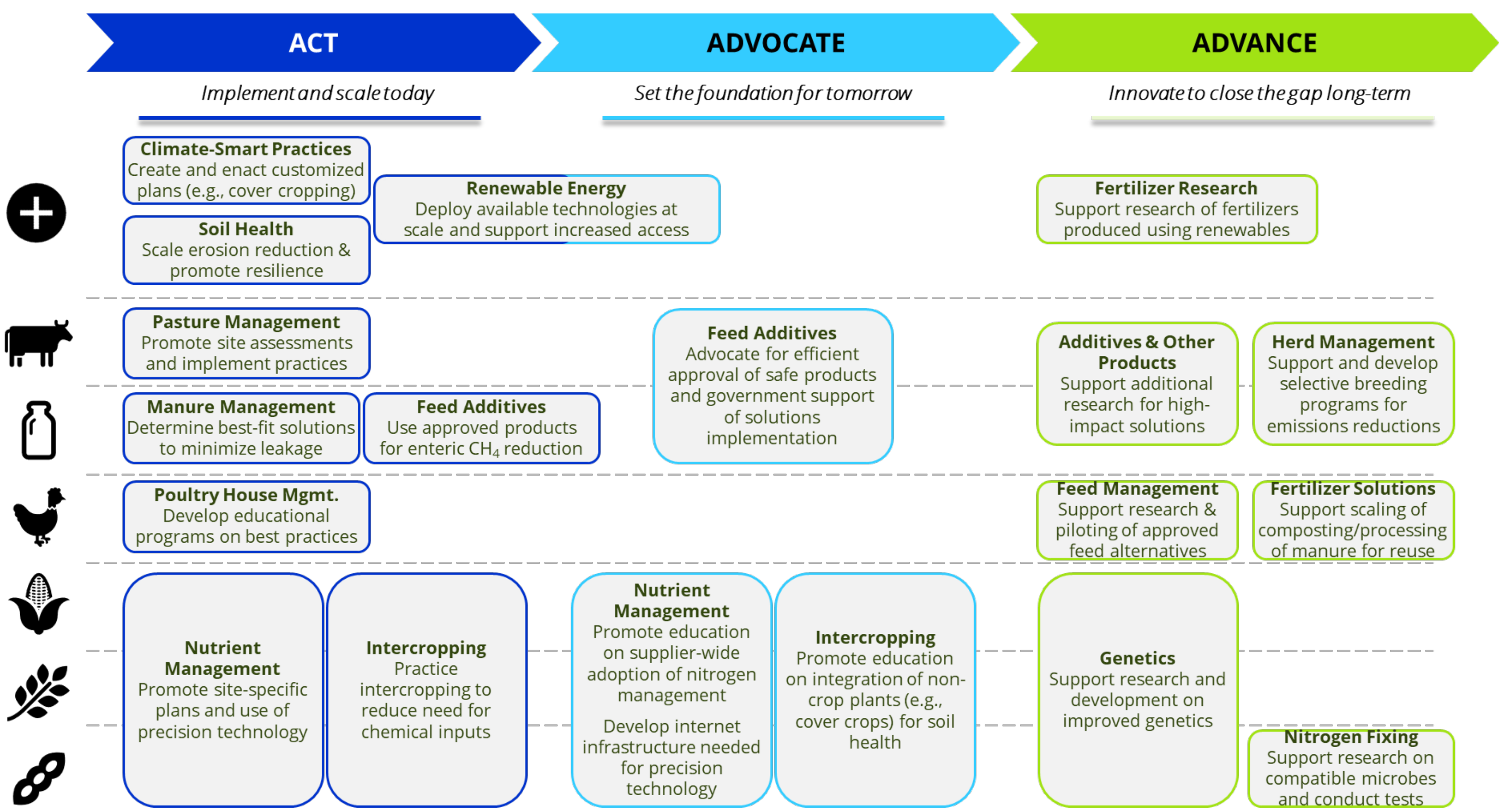
With a plethora of solutions of varying readiness on the table, FLAG companies must make informed decisions on how to invest their time and resources. Some solutions can be operationalized immediately, while others show sufficient promise to warrant continued acceleration of R&D and investment. Figure 21 below sequences solutions based on how companies should engage **today.**

Achieving the transformation required across the food system will take tremendous – and collaborative – effort. While the scale of change required can seem daunting, and even as regulations, guidance, and innovations continue to evolve, it remains critical to act now.

Companies can create the most productive emissions reduction strategies for managing non-land use change emissions by utilizing the gas-specific approach outlined in this report.

By accounting for the varying characteristics, including global warming potential and atmospheric lifespan, of different greenhouse gases, particularly methane and nitrous oxide, companies will be better equipped to set informed science-based targets and drive greater impact.

Figure 21: Act, Advocate, Advance Prioritization of Actions



Agriculture has been known to move and adopt quickly in the past. Working with upstream growers and ranchers is critical to downstream companies managing climate impacts in their value chains and achieving FLAG targets. Technical support and financial incentives are two key elements of producer support that must be thoughtfully constructed with inputs across FLAG players to manifest as both practical and attractive. For target-setting companies with suppliers in the Global South, it will be particularly essential to provide fair and equitable support that alleviates time and human capital burdens on suppliers. Across regions, exploring opportunities for ecosystem collaboration will be vital for the collective success of players across the sector. Taking strategic, actionable steps, seeking creative partnerships, and empowering stakeholders across the agriculture value chain will form the foundation for our collective success.

At the time of writing this report, SBTi FLAG guidance continues to evolve, and companies eagerly await validation on target aspects from the Greenhouse Gas Protocol (GHGP). Yet, beyond FLAG targets lies the sector's ongoing imperative to supply food to a growing population on a finite land area. Companies cannot afford to waste a moment in adopting solutions to make food production sustainable for years to come.

Ecosystem Collaboration

General Mills partnered with The National Fish and Wildlife Foundation (NFWF) beginning in 2021 to accelerate the adoption of climate-smart agriculture to improve soil health and water quality. The partnership supports the hiring of field conservation professionals to work directly with landowners in the Great Lakes Basin and Great Plains. The program enables locally-led assistance tailored to each producer's goals, experience, and risk tolerance in advancing conservation actions such as cover crops, crop rotation, and conservation tillage. The partnership also emphasizes the convening of local farmer-led groups to engage in peer-to-peer learning and shared conservation planning.

Within two years, the Conservation Program has opened funding opportunities to other FLAG companies such as Cargill and Nestle, strengthening NFWF's capacity to award competitive grants to recipients with existing trusted relationships with landowners and operators. These convening organizations use the grants to offer technical assistance to their network of growers seeking to participate in management plans and Farm Bill programs.

Resources and tools for Implementation

For planning: In addition to guidance, SBTi has created an Excel-based tool designed to help FLAG companies develop near-term science-based targets. Long-term targets should be set using the Net Zero tool. As of February 2024, the Greenhouse Gas Protocol is working to release Land Sector and Removals Guidance aimed at clarifying how companies can account and report on emissions reductions and removals related to land management, land use change, biogenic products, and removal technologies.

For measurement and accounting: There are several companies which offer step-by-step guidance for assessing, monitoring, reporting and verification of FLAG emissions along sector- and commodity-specific pathways, advertising capabilities to quantify previously elusive land use change and land management emissions by commodity. Investment in the collection of high quality, high resolution data can robustly track progress towards emissions targets and will improve understanding of the best pathways towards reaching them. Additionally, the Cool Farm Tool created by a pre-competitive alliance of companies and NGOs offers decision support to help farmers run "what-if" scenarios and develop action plans to reduce greenhouse gas emissions.

For sector collaboration: There are several regional, national, and global coalitions companies can consider joining and supporting to magnify advocacy and research efforts—so many that coalition strategies could constitute another report altogether! Global Research Alliance on Agriculture Greenhouse Gases is one of many active coalitions striving to facilitate knowledge exchange and advocacy efforts related to FLAG emissions reduction. Companies should consider the objectives, existing members, and focus areas of coalitions when deciding on how to channel sector-wide collaboration efforts.

For grower support: In the U.S., the Foundation for Food & Agriculture Research (FFAR) and the U.S. Farmers & Ranchers Alliance (USFRA) have invested millions in projects to test actionable climate solutions by geography, farm type, crop, and livestock and seeking partnerships to match funds and expand their program. The USDA also offers voluntary programs and services to help growers incorporate climate-smart agriculture into their operations, notably investing $1 billion into its Climate-Smart Commodities program. The Government of Canada has invested heavily into climate-action agriculture initiatives such as the Agricultural Clean Technology Program and has endeavored better understand farmer needs through initiatives such as the "What We Heard" report regarding its fertilizer emissions reduction target. The EU offers eco-schemes that meet payments to farms qualifying under a published set of climate-smart practices under their common agricultural policy (CAP), whose Strategic Plans will also include farm advisory services.

ACKNOWLEDGEMENTS

This report would not have been possible without the insights and support provided by the commissioned Advisory Committee, which included expert representatives from leading organizations across the FLAG sector. Advisory Committee members included:

- Chris Adamo, VP of Public Affairs and Regenerative Agriculture Policy, Danone
- John Lee, Director of Missions & Sustainability, Nature, Danone
- Justin Ransom, Senior Director of Sustainable Food Strategy, Tyson Foods
- Jordan Sabine, US Supply Chain Sustainability, McDonalds
- Steve Rosenzweig, Principal Scientist, General Mills
- Monica McBride, Director of Partnerships, Bayer
- Kurt Alles, Head of Sustainable Business, Farmers Business Network
- Coralie Pierre, Senior Manager of Programs & Partnerships, Field to Market
- Melissa Gallant, North America Soil Health & Nutrients Strategy Manager, The Nature Conservancy

Thank you to our partners for their collaboration and valuable contributions to this work

APPENDIX

SBTi FLAG Guidance

The full SBTi FLAG guidance and target criteria may be found here: SBTiFLAGGuidance.pdf (sciencebasedtargets.org)

Report Methodology

LIFE CYCLE ASSESSMENT (LCA) META ANALYSIS

This report builds upon SBTi's FLAG guidance to define potential decarbonization pathways for six FLAG commodities in the United States, Canada, European Union, and United Kingdom: beef, dairy, poultry (specifically broiler chickens), corn, soy, and wheat. These pathways were developed after conducting a meta-analysis of selected life-cycle assessments (LCAs) to determine the roles that nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) have on the underlying emissions drivers for each commodity relative to each gas' respective global warming potential (GWP).

The full details on the scope of the report can be found in the Report Scope section.

Abatement Solution Evaluation Criteria

FLAG sector emissions reduction solutions were assessed for recommendation by scoring against three criteria:

1. Solution's relevance to commodity's top emissions drivers by intensity (with consideration given to GWP of addressed greenhouse gas)
    a. Score of 4: Solution addresses primary/highest emissions driver based on intensity
    b. Score of 3: Solution addresses second highest emissions driver based on intensity
    c. Score of 2: Solution addresses third highest emissions driver based on intensity
    d. Score of 1: Solution addresses fourth and final emissions driver based on intensity
2. Solution's maximum estimate for abatement potential (% reduction of emissions of the greenhouse gases tied to the emissions driver the solution targets) found in meta-analysis research (sources linked in Abatement Analysis Literature Appendix below)
    a. Score of 4: Highest abatement potential, greater than 50%
    b. Score of 3: High abatement potential, 30-50%
    c. Score of 2: Medium abatement potential, 10-29%
    d. Score of 1: Low abatement potential, less than 10%

    Please note: the solution's maximum abatement potential estimates the percentage reduction that solution could contribute relative to the emissions driver the solution is tied to.
3. Solution's estimated commercial availability based on meta-analysis research, testing with the Advisory Committee for the report (see Acknowledgements below), and validation with EDF scientists

For the third criterion, Table 9 lists the phase definitions of solution maturity and commercial availability used as a part of solution scoring:

Table 9: Solution Maturity Definitions

Phase	Definition
1 Prototype	Solution prototyped and proven in lab or controlled conditions; not yet deployed commercially
2 Initial Commercialization	Solution introduced as a functional commercial unit; ad-hoc deployment by limited number of customers and financiers; not yet financially competitive
3 Early Adoption	Solution commercially available but requires improvements to increase competitiveness; costs (e.g., green premiums) and performance gaps remain; further integration with FLAG sector needed
4 Broad Adoption	Solution has achieved stable and predictable commercialization and has scaled in the market; at par (in terms of price and performance) with carbon-emitting alternatives

The following evaluation of solutions is intended to inform the recommendations of this report and thus support companies' strategic prioritization of actions to reduce emissions within their value chains. It is essential that companies consider the unique aspects of their individual value chains when deploying solutions and determining what will be most appropriate and effective for their businesses and the regions within their footprint. Additionally, the deployment of one practice to reduce one source of greenhouse gas emissions can have the unintended consequences of increasing emissions elsewhere; while this report cannot capture all potential interactions, it is a critical consideration for implementation.

Abatement Solution Evaluation

Table 10: Beef Abatement Solution Evaluation

Solution	Description	Relevant Driver	Max Abatement Potential	Commercial Availability	Primary Relevant GHGs
Manure management techniques	Use of techniques that reduce methane emissions in manure through improved pasture management and grazing diets	Manure management (3)	Highest (60%) (4)	Broad adoption (4)	CH_4, N_2O
Feed additives	Use of feed additives to target digestive microorganisms or otherwise inhibit CH_4	Enteric Fermentation (4)	High (30%) (3)	Initial commercialization (2)	CH_4
Herd management	Optimization of practices in breeding, feeding, and care; includes use of anti-methanogen vaccines	Enteric fermentation (4)	High (30%) (3)	Initial commercialization (2)	CH_4
Sustainable land management*	Use of climate-smart practices (e.g., cover crops, agroforestry, soil enhancement) to reduce upstream emissions from feed	Feed (2)	High (50%) (3)	Early adoption (3)	CO_2, N_2O
Feed alternatives	Use of alternative, less emission-intensive feed sources (e.g., plant-based substitutes, algae, insect meal)	Feed (2)	High (30%) (3)	Initial commercialization (2)	CO_2, N_2O
Energy efficiency	Adoption of energy-saving technologies in lighting, livestock waterers, ventilation fans, etc.	Direct energy use (1)	Medium (15%) (2)	Broad adoption (4)	CO_2
Alternative fuels	Use of biodiesel, biogas, or electric vehicles for farming equipment	Direct energy use (1)	Highest (85%) (4)	Initial commercialization (2)	CO_2
Carbon / methane capture systems	Use of systems to capture and sequester emissions from waste storage areas	Manure Management (4)	Variable / unknown (1)	Initial commercialization (2)	CH_4
Precision feeding/ nutrition optimization	Optimization of feeding practices to reduce waste and increase efficiency	Feed (2)	Medium (20%) (2)	Early adoption (3)	CO_2, N_2O
Renewable energy	Use of renewable energy sources (e.g., wind, solar) for beef production, based on availability	Direct energy use (1)	Variable / unknown (1)	Broad adoption (4)	CO_2
Operational efficiencies	Use of automated systems (e.g., sensors/ IoT devices to monitor pastures and grazing patterns) to optimize activities	Direct energy use (1)	Medium (20%) (2)	Early adoption (3)	CO_2

**Sustainable land management practices are embedded as solutions within the Climate-Smart Agriculture recommendation in the report*

Table 11: Dairy Abatement Solution Evaluation

Solution	***Description***	***Relevant Driver***	***Max Abatement Potential***	***Commercial Availability***	***Primary Relevant GHGs***
Manure management	Use of techniques that reduce emissions of methane during storage, treatment, and application of manure	Manure management (3)	Highest (60%) (4)	Broad adoption (4)	CH_4, N_2O
Feed additives	Use of feed additives to target digestive microorganisms or otherwise inhibit CH_4	Enteric Fermentation (4)	High (30%) (3)	Initial commercialization (2)	CH_4
Herd management	Optimization of practices in breeding, feeding, and care; includes use of anti-methanogen vaccines	Enteric fermentation (4)	High (30%) (3)	Initial commercialization (2)	CH_4
Sustainable land management*	Use of climate-smart practices (e.g., cover crops, agroforestry, soil enhancement) to reduce upstream emissions from feed	Feed (2)	High (50%) (3)	Early adoption (3)	CO_2, N_2O
Feed alternatives	Use of alternative, less emission-intensive feed sources (e.g., plant-based substitutes, algae, insect meal)	Feed (2)	High (30%) (3)	Initial commercialization (2)	CO_2, N_2O
Energy efficiency	Adoption of energy-saving technologies in milking equipment, milk cooling and storage, lighting, livestock waterers, etc.	Direct energy use (1)	Medium (15%) (2)	Broad adoption (4)	CO_2
Alternative fuels	Use of biodiesel, biogas, or electric vehicles for farming equipment	Direct energy use (1)	Highest (85%) (4)	Initial commercialization (2)	CO_2
Carbon / methane capture systems	Use of systems to capture and sequester emissions in waste storage areas	Enteric fermentation (4)	Variable / unknown (1)	Initial commercialization (2)	CH_4
Precision feeding/ nutrition optimization	Optimization of feeding practices to reduce waste and increase efficiency	Feed (2)	Medium (20%) (2)	Early adoption (3)	CO_2, N_2O
Renewable energy	Use of renewable energy sources (e.g., wind, solar) for dairy production, based on availability	Direct energy use (1)	Variable / unknown (1)	Broad adoption (4)	CO_2
Operational efficiencies	Use of automated systems (e.g., robotic milking, IoT devices for precision ag.) to optimize activities	Direct energy use (1)	Medium (20%) (2)	Early adoption (3)	CO_2

**Sustainable land management practices are embedded as solutions within the Climate-Smart Agriculture recommendation in the report*

Table 12: Chicken Abatement Solution Evaluation

Solution	Description	Relevant Driver	Max Abatement Potential	Commercial Availability	Primary Relevant GHGs
Feed management	Use of precision feeding and other techniques to enhance feed efficiency and reduce emissions from feed production, including feed alternatives	Feed (4)	High (35%) (3)	Early adoption (3)	CO_2, N_2O
Renewable energy*	Use of renewable energy sources (e.g., wind, solar) for chicken production, based on availability	Direct energy use (3)	High (30%) (3)	Broad adoption (4)	CO_2
Sustainable land management**	Use of climate-smart practices (e.g., cover crops, agroforestry, soil enhancement) to reduce upstream emissions from feed	Feed (4)	High (50%) (3)	Early adoption (3)	CO_2, N_2O
Manure management*	Use of techniques that reduce emissions during storage, treatment, and application of manure	Manure management (2)	Highest (60%) (4)	Early adoption (3)	CH_4, N_2O
Energy efficiency	Adoption of energy-saving technologies in housing, ventilation, water use, monitoring, etc.	Direct energy use (3)	Medium (15%) (2)	Broad adoption (4)	CO_2
Animal management	Use of techniques to improve hatchery management, including genetic improvements	Embedded energy use (1)	Medium (10%) (2)	Initial commercialization (2)	CO_2
Bedding / litter material management	Use of alternative materials in indoor housing systems to reduce emissions	Embedded energy use (1)	High (40%) (3)	Initial commercialization (2)	CO_2

**Renewable energy, manure management, and litter management were included as solutions under the overall recommendation of poultry house management in the report*

***The practice of composting poultry manure to fertilizer was used as a recommendation for the report as an application of sustainable land management practices*

Table 13: Corn Abatement Solution Evaluation

Solution	Description	Relevant Driver	Max Abatement Potential	Commercial Availability	Primary Relevant GHGs
Green / bio-fertilizers	Use of bio-based (e.g., compost) or green fertilizers (e.g., made with renewable energy)	Field emissions (4)	Highest (80%) (4)	Initial commercialization (2)	N_2O
Sustainable land management*	Use of climate-smart practices (e.g., cover crops, agroforestry, soil enhancement)	Field emissions (4)	High (40%) (3)	Early adoption (3)	CO_2, N_2O
Precision agriculture*	Use of automation and technology (e.g., sensing, IoT) to optimize fertilizer application and other practices	Field emissions (4)	Medium (20%) (2)	Early adoption (3)	N_2O
Renewable energy	Use of renewable energy sources (e.g., wind, solar) for crop production, based on availability	Machinery, equipment, and fuel (3)	Variable / unknown (1)	Broad adoption (4)	CO_2
Enhanced efficiency fertilizers	Application of slow-release N fertilizers or inhibitors to optimize soil health	Field emissions (4)	Variable / unknown (1)	Early adoption (3)	N_2O
Alternative fuels	Use of biodiesel, biogas, or electric vehicles for farming equipment	Machinery, equipment, and fuel use (3)	High (30%) (3)	Initial commercialization (2)	CO_2
Agri-genomics	Modifications of crop genetics and crop selections to increase efficiency	Other field inputs (1)	High (45%) (3)	Early adoption (3)	CO_2
Basalt rock spreading	Use of negative emission technology to boost CO_2 removal from the atmosphere	Field emissions (4)	Variable / unknown (1)	Prototype (1)	N_2O
Biochar application	Application of biochar to reduce field emissions	Field emissions (4)	Variable / unknown (1)	Prototype (1)	N_2O

**Sustainable land management and Precision agriculture are grouped as solutions within the Climate-Smart Agriculture recommendation in the report. Variable rate technology, an application of precision agriculture, and agri-genomics have been recommended as additional solutions pertinent to Corn.*

Table 14: Soy Abatement Solution Evaluation

Solution	Description	Relevant Driver	Max Abatement Potential	Commercial Availability	Primary Relevant GHGs
Green / bio-fertilizers	Use of bio-based (e.g., compost) or green fertilizers (e.g., made with renewable energy)	Field emissions (4)	Highest (80%) (4)	Initial commercialization (2)	N_2O
Sustainable land management*	Use of climate-smart practices (e.g., cover crops, agroforestry, soil enhancement)	Field emissions (4)	High (40%) (3)	Early adoption (3)	CO_2, N_2O
Precision agriculture*	Use of automation and technology (e.g., sensing, IoT) to optimize fertilizer application and other practices	Field emissions (4)	Medium (20%) (2)	Early adoption (3)	N_2O
Renewable energy	Use of renewable energy sources (e.g., wind, solar) for crop production, based on availability	Machinery, equipment, and fuel (3)	Variable / unknown (1)	Large scale (4)	CO_2
Enhanced efficiency fertilizers	Application of slow-release N fertilizers or inhibitors to optimize soil health	Field emissions (4)	Variable / unknown (1)	Early adoption (3)	N_2O
Alternative fuels	Use of biodiesel, biogas, or electric vehicles for farming equipment	Machinery, equipment, and fuel use (3)	High (30%) (3)	Initial commercialization (2)	CO_2
Agri-genomics	Modifications of crop genetics and crop selections to increase efficiency	Other field inputs (1)	High (45%) (3)	Early adoption (3)	CO_2
Basalt rock spreading	Use of negative emission technology to boost CO_2 removal from the atmosphere	Field emissions (4)	Variable / unknown (1)	Prototype (1)	N_2O
Biochar application	Application of biochar to reduce field emissions	Field emissions (4)	Variable / unknown (1)	Prototype (1)	N_2O

**Sustainable land management and Precision agriculture are grouped as solutions within the Climate-Smart Agriculture recommendation in the report. Intercropping, an application of sustainable land management, and enhanced efficiency fertilizers have been recommended as particularly pertinent solutions to Soy; intercropping is an important conservation practice for all crops in non-irrigated systems.*

Table 15: Wheat Abatement Solution Evaluation

Solution	***Description***	***Relevant Driver***	***Max Abatement Potential***	***Commercial Availability***	***Primary Relevant GHGs***
Green / bio-fertilizers	Use of bio-based (e.g., compost) or green fertilizers (e.g., made with renewable energy)	Field emissions (4)	Highest (80%) (4)	Initial commercialization (2)	N_2O
Sustainable land management*	Use of climate-smart practices (e.g., cover crops, agroforestry, soil enhancement)	Field emissions (4)	High (40%) (3)	Early adoption (3)	CO_2, N_2O
Precision agriculture*	Use of automation and technology (e.g., sensing, IoT) to optimize fertilizer application and other practices	Field emissions (4)	Medium (20%) (2)	Early adoption (3)	N_2O
Enhanced efficiency fertilizers	Application of slow-release N fertilizers or inhibitors to optimize soil health	Field emissions (4)	Variable / unknown (1)	Early adoption (3)	N_2O
Renewable energy	Use of renewable energy sources (e.g., wind, solar) for crop production, based on availability	Machinery, equipment, and fuel (2)	Variable / unknown (1)	Broad adoption (4)	CO_2
Alternative fuels	Use of biodiesel, biogas, or electric vehicles for farming equipment	Machinery, equipment, and fuel use (2)	High (30%) (3)	Initial commercialization (2)	CO_2
Agri-genomics	Modifications of crop genetics and crop selections to increase efficiency	Other field inputs (1)	High (45%) (3)	Early adoption (3)	CO_2
Basalt rock spreading	Use of negative emission technology to boost CO_2 removal from the atmosphere	Field emissions (4)	Variable / unknown (1)	Prototype (1)	N_2O
Biochar application	Application of biochar to reduce field emissions	Field emissions (4)	Variable / unknown (1)	Prototype (1)	N_2O

**Sustainable land management and Precision agriculture are grouped as solutions within the Climate-Smart Agriculture recommendation in the report. Precision agriculture has also been included under a wheat-specific recommendation for site-specific nutrient management, along with agri-genomics.*

"Commodity A" Illustrative Growth Rate Analysis

Table 16: Impact of Growth Rate on Absolute Emissions and Emissions Intensity for Generic Commodity A

	Baseline intensity emissions (t CO_2e / t fresh weight or FPCM)	2035 intensity target (t CO_2e / t fresh weight or FPCM)	% intensity reduction from baseline to 2035	Growth rate 2019 - 2035	Starting amount total product (t fresh weight or FPCM)	Absolute emissions at start w/ baseline emissions intensity	End amount total product based on growth rate (t fresh weight or FPCM)	Absolute emissions at end w/ intensity reduction target achieved	Net % change in absolute emissions
Commodity A	1	0.48	52%	0%	100	100	100	48.2	**-52%**
Commodity A	1	0.48	52%	25%	100	100	125	60.2	**-40%**
Commodity A	1	0.48	52%	50%	100	100	150	72.3	**-28%**
Commodity A	1	0.48	52%	75%	100	100	175	84.4	**-16%**
Commodity A	1	0.48	52%	100%	100	100	200	96.6	**-3%**
Commodity A	1	0.48	52%	125%	100	100	225	108.7	**9%**
Commodity A	1	0.48	52%	150%	100	100	250	120.9	**21%**

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2. "The SBTi launches the world's first standard method to cover land-related emissions and removals," Science Based Targets (n.d.)
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9. Global Warming Potentials can be defined as how much energy an emission of 1 ton of a gas 'will absorb over a given period of time, relative to 1 ton of CO_2'; these values allow the comparison of the emissions of various gasses and their estimated impact on global warming.
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