Agricultural Solutions for Reducing GHG Emissions and Sequestering Carbon

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Natural and Working Land Task Force
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Prepared on behalf of:

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Executive Summary

As the State of Colorado Natural and Working Land Task Force develops the strategic plan that will guide future greenhouse gas (GHG) emission reductions and carbon sequestration goals, targets, and policies across Colorado agricultural lands, it is imperative that decisions are backed by scientifically credible information. On January 14, 2021, Colorado released a Greenhouse Gas (GHG) pollution Reduction Roadmap that outlined Colorado's largest GHG emissions by sector and proposed GHG reduction goals for 2025 and 2030.The Colorado Greenhouse Gas Pollution Reduction Roadmap has a goal to reduce 1 million metric tons (mmt) of GHG emission on all Natural and Working Lands by 2030 (CO 2021). Natural and Working Lands are characterized as forests, grasslands, agricultural croplands and rangelands, riparian areas, and urban greenspaces. As the leading agricultural producer in the state, Weld County commissioned this report to detail available opportunities to reduce GHG emissions in production agriculture in Weld County to help meet the 1 mmt reduction target and with the goal of expanding programs and best practices across the State of Colorado. The paper aims to:

1. Explain how climate, soils, and management type impact GHG emissions within croplands
2. Explain the sources of emissions from livestock operations
3. Recommend strategies for policy makers to sequester carbon and/or reduce GHG emissions in the agricultural sector across three areas of focus:
    a. Crop, Feed, and Fuel Production from farming activities
    b. Increase awareness of solutions for methane emissions from enteric fermentation in ruminants
    c. Manure Management from livestock operations.

Weld County engaged The Context Network, (Context), to identify the areas of greatest opportunity to make a positive environmental impact in Colorado and synthesize strategies for State officials and sustainability professionals to develop a roadmap for education and implementation of best practices within the agricultural sector. Table 1 below shows the estimated potential of interventions to reduce GHG emissions in Weld County. These should be considered more as directional values than absolutes. Further research to explore and further quantify the impacts of recommended interventions is recommended.

Table 1: Potential CO_2 reduction by Mitigation Strategy in Weld County, Colorado.

Weld County Mitigation Strategy	Agricultural Type	Estimated Total Reduction Tonnes/Year
Intensive tillage to no-till or strip-till on irrigated lands	Cropland	128,261
Intensive tillage to no-till or strip-till on non-irrigated lands	Cropland	43,065
Legume cover crop with 50% reduction in N on irrigated lands	Cropland	61,204
Legume cover crop with 50% reduction in N on non-irrigated lands	Cropland	0

Weld County Mitigation Strategy	Agricultural Type	Estimated Total Reduction Tonnes/Year
Replace synthetic N with feedlot manure on irrigated lands	Cropland	39,783
Replace synthetic N with feedlot manure on non-irrigated lands	Cropland	3,445
Agolin for cattle on feed	Animal	55,000
Bovaer for cattle on feed (once commercially available)	Animal	275,000
Agolin for dairy cattle	Animal	36,667
Bovaer for dairy cattle (once commercially available)	Animal	110,000
The total reduction estimates are intended to provide directional values rather than absolutes. The cropland reduction estimates are based on Census of Agriculture (USDA, 2017) and data pulled from Comet-Planner™. Animal agriculture estimates are based on 2020 Colorado Cattle inventory Estimates (USDA, 2021) and research (Belanche et al., 2020; Hiar, 2021) on efficacy of feed additives to reduce enteric methane emissions. For both crop and animal agriculture, estimates were based on applying the technology or practice to all acres or all livestock, which is not realistic in practice.		

Recommended Strategies

1. Develop an economic model to determine the approximate annualized cost per ton of cropland and animal agriculture strategies and compare those to a benchmark value, i.e. carbon market price or a social cost of carbon or alternative projects.
2. Evaluate production practices in both irrigated and non-irrigated systems to quantify the potential for the generation of carbon credits across the county.
    - Conduct surveys to determine the current level of adoption of practices using a combination of in-person surveys and satellite imagery.
    - Incorporate data obtained from the surveys into an assessment that evaluates 1) the potential for carbon credits based on producers' production practices; and 2) the potential economic benefit of generating carbon credits to the county and to producers.

Guiding Framework For Program Development And Strategic Alliances

1. Seek to understand
2. Reflect what we hear
    a) **Respect**
    b) **Appreciation**
    c) **Recognition**
3. Share the vision
    a) **Positive voluntary opportunities, not penalties**
4. Seek alignment

3. Explore feasibility and develop programs to encourage the use of agricultural carbon markets within the confines of the State of Colorado mandates and restrictions
    - Develop a program where county governments would act as an aggregator/broker into the ag carbon markets for producers within their county, presenting a pool of carbon credits of sufficient volume to enable a more favorable contract than a single producer would be able to negotiate.
    - Explore different carbon registries to learn what is required for the development and

verification of ag carbon credits within the county.
  - Evaluate the resources, human and capital, required to implement a county-level scale aggregation of ag carbon credits.
  - Determine the potential ag carbon credits within the county available for the ag carbon markets.
4. Develop a communication and education program for producers.
  - Develop fact sheets on ag carbon markets for producers.
  - Educate producers about the potential ag carbon credits generated and benefit of adoption of new practices on producers' economic returns.
  - Conduct in-person seminars on production practices contributing to ag carbon reductions and the benefit to both the environment and producers.
  - Assist producers in evaluating their current practices and strategies for adopting changes in management over time along with assistance in adaptive management programs on a yearly schedule.
  - Raise awareness thereby supporting enrollment in programs like the National Resource Conservation Service (NRCS) Environmental Quality Incentive Program (EQIP) that provides payments to farmers and ranchers for adopting practices that reduce their environmental footprint, often up to 75% of the practice cost. The community-based orientation of farms and farmers provides a great platform for Weld County.
5. Encourage the use of Anaerobic Digestors (AD) for manure management at dairy farms to assist in reducing CO_2 equivalent by commissioning an Anaerobic Digester Resource Guide to give Coloradoans a glimpse of the emerging RNG industry, as well as its many job opportunities and new markets for livestock generated environmental benefits.
6. Develop relationships with scientifically credible environmental non-governmental organizations (NGOs), like the Environmental Defense Fund, for example. These organizations can help focus scientific resources to drive feed additive innovations that reduce enteric methane emissions. Collaborating with certain NGOs often provides the political and public relations clout necessary to reach critical mass with non-agriculture audiences.

Assist producers in evaluating their current practices and strategies for adopting changes in management over time along with assistance in adaptive management programs on a yearly schedule.

7. Collaborate with producers and counties to provide input and develop tools and practices to achieve GHG reductions
  - Improve consultation with leading agriculture producing counties by forming a collaborative working group comprised of officials at both the State and local levels along with agricultural producers and academic researchers as CDPHE develops the desired GHG dashboard.
  - Provide a forum for Weld County to provide input into CDPHE on the tools being used to

measure and report on practices and technologies used to achieve GHG reductions and carbon sequestration.

8. Collaborate with other livestock important states and organizations and call on Congress and the Administration to either have FDA Center for Veterinary Medicine recategorize Bovaer as a feed additive instead of a drug or expedite the agencies review of Bovaer and other potential climate-focused products. This will allow for a product that is scientifically proven to reduce enteric emissions by at least 30% to be used immediately within animal agriculture.

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Section 1:

Introduction

Agriculture is dominant in Weld County with over 1.975 million acres devoted to farming and raising livestock (2017 Agriculture Census). Weld County is Colorado's leading producer of beef cattle, grain, sugar beets, and the state's leading dairy producer. Colorado is the 16th largest dairy state in the nation and is expected to increase production in the coming years. As the leading agricultural county in Colorado, Weld County is uniquely positioned to:

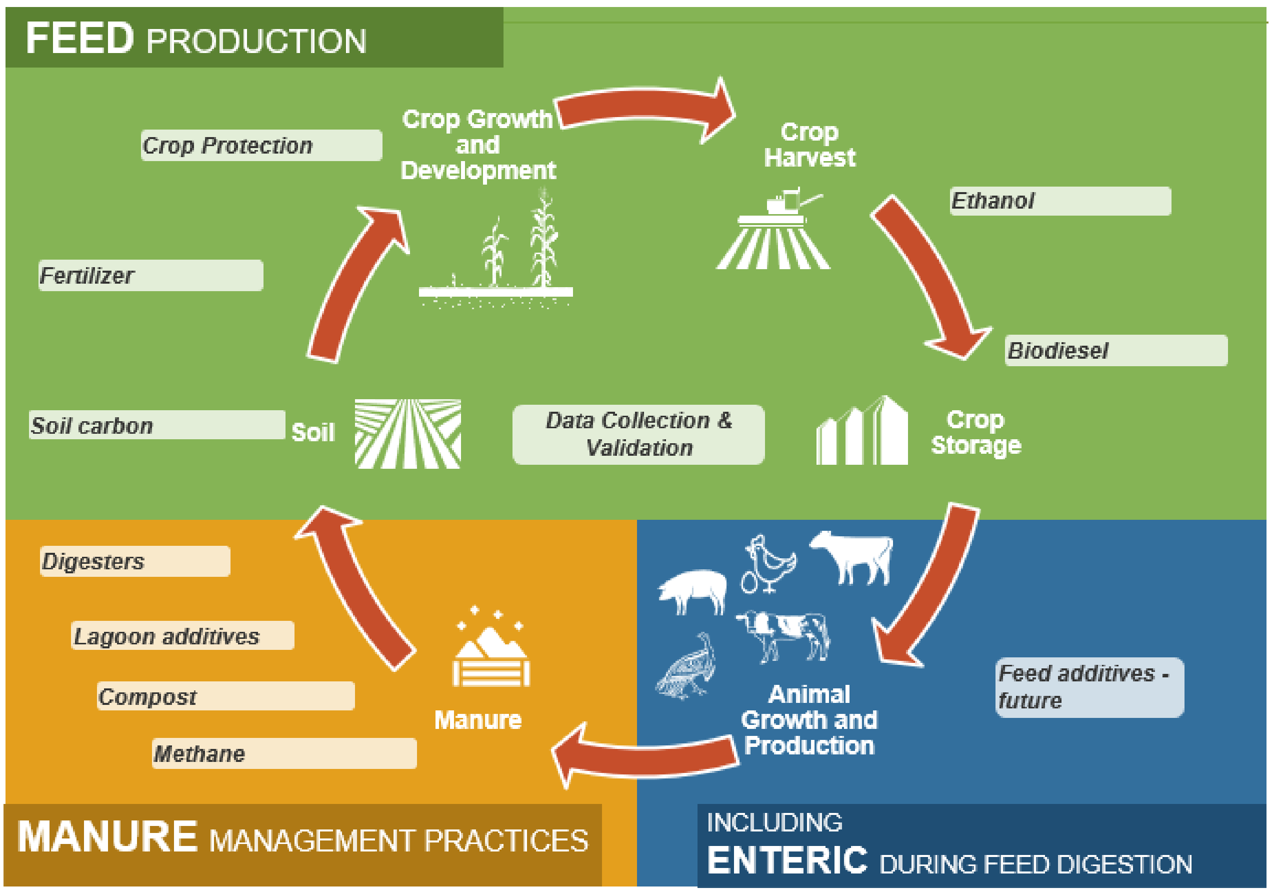
1. proactively collaborate with the Natural and Working Lands (NWL) Task Force in developing the Strategic Plan to explore and promote best practices to reduce GHG emissions.
2. provide guidance and expertise through the Context Network, a global leader in agricultural science.
3. help bridge engagement between the state and counties, constituents, and communities.

Given the landscape, production activities, and resources in Weld County, Context has identified three primary areas to accomplish GHG emissions reductions, soil carbon sequestration, and policy development: (1) Crop, Feed, and Fuel Production from farming activities, (2) Enteric Fermentation, and (3) Manure Management from beef and dairy production (Figure 1). This report provides recommended mitigation strategies for these three areas and includes additional recommendations related to the development of carbon monetization and supporting the NWL task force.

Agricultural Carbon Cycle

The agricultural carbon cycle encompassing crop and animal production systems depicts the flow of carbon from crop uptake via photosynthesis through the utilization as feed stocks by the animal production system. Carbon is transferred around this cycle to produce a variety of products providing feed, fuel, meat, milk, or eggs with the potential to modify the loss of GHGs through carbon sequestration in the soil, more efficient nitrogen management to affect nitrous oxide losses, and animal diets and manure storage to reduce methane emissions. The ability to capture the GHG dynamics in agricultural enterprises requires robust data collection, interpretation, and validation.

Figure 1: Agricultural carbon cycle in crop and animal production systems with the parts of the overall cycle where inputs are used and products can be generated.



Section 2:

GHG Sequestration in Cropland Agriculture

Profile of Weld County Cropland Agriculture

The development of strategies that could reduce agriculture's carbon footprint requires an understanding of the current cropping practices. Information from the Census of Agriculture, published in 2017, provides a breakdown of crops grown and the portion of the crop produced under irrigated conditions. Table 2 outlines this distribution.

Winter wheat production in the county occurs under dryland or rainfed conditions, as does sorghum and proso millet for grain. The remainder of the crops produced in the county utilize irrigation. Irrigated crops, which are currently about 2/3 of the cropland in Weld County, provide an opportunity to sequester carbon or reduce GHG emissions. Specific strategies that have the potential to be effective include changes to tillage, crop rotation, cover crops, and fertilization, including nitrogen management.

Table 2: Crop distribution demographics in Weld County, Colorado (Census of Agriculture 2017, USDA).

Crop	Total Acres	Irrigated Acres	Irrigated Fraction
Forage	134,532	104,301	0.78
Wheat, winter	110,603	15,395	0.14
Corn, grain	105,651	89,123	0.84
Corn, silage	65,970	56,383	0.85

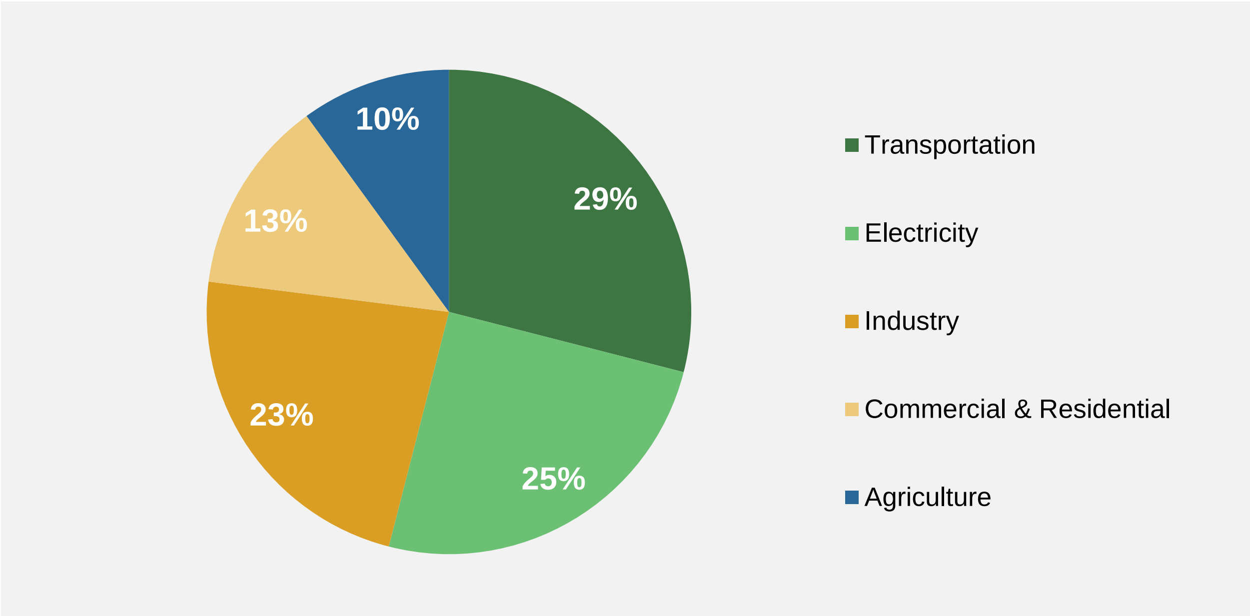
Crop	Total Acres	Irrigated Acres	Irrigated Fraction
Sugarbeet	14,520	14,520	1
Proso Millet	13,312	0	0
Vegetables	9,471	9,471	1
Dry Beans	9,075	8,102	0.89
Barley	6,282	5,812	0.92
Sunflower	3,692	1,408	0.38
Sorghum, chop	1,619	1,291	0.8
Sorghum, grain	1486	0	0
Oats	1,046	116	0.11
Wheat, spring	501	0	0
Triticale	420	0	0
Total	**478,180**	**305,922**	**0.64**

Implementation of any strategy related to crop production has to consider the climate of the region. Annual precipitation in Weld County averages 14.6 inches per year, with most rainfall occurring from April to September (National Climate Data Center, NOAA). The remainder of the year averages 1.7 inches for the October to March period. Average maximum temperatures range from 39°F in December and January to 85°F in July, with minimum temperatures ranging from 14°F in December and January to 58°F in July and August. Minimum temperatures are below 32°F from late October through early April. Rainfall patterns represent an essential aspect of potential plant growth, in addition to the typical growing season. Precipitation totals show the need for irrigation to produce grain and forage required to meet the needs of the livestock industry in Weld County. Irrigated cropland has the potential for management practices that would increase carbon sequestration. The temperature patterns of Weld County also show that practices linked to growing longer season crops or cover crops may not be viable because of the lack of growth during the winter.

GHG Dynamics in Cropland Agriculture

Agriculture contributes roughly 10% of total GHG emissions in the United States (Figure 2; EPA 2019). Three GHGs are emitted from agriculture production—carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Methane has 32 times the warming potential as CO_2 and N_2O has 265 times that of CO_2 showing that practices that reduce these two gases will contribute significantly to a reduction in GHG emission. In crop production agriculture, CO_2 is the focus for sequestration efforts, while N_2O is associated with nitrogen management focusing on emission reduction strategies. (See Section 3 for more information about CH_4.)

Figure 2: Sources of United States GHG emissions by economic section in 2019. *Adapted from EPA 2019.*



CO_2 emissions are affected by crop rotation sequences and tillage practices while sequestration is dependent upon implementing management practices that result in a positive carbon balance into the soil. The carbon balance in cropland systems represents the dynamics of the ability of a crop to capture sunlight, CO_2, and water through photosynthesis, creating sugars later transformed into various compounds. A portion of these sugars move to the roots, leaking into the soil and providing energy for plants to grow. The carbon balance is simply a result of the amount of carbon captured during the year minus what is lost. Losses of carbon can occur through respiration, tillage, and water or wind erosion. The longer a growing plant is covering the soil surface, the greater the potential for capturing carbon. Conversely, the greater the tillage intensity, the greater the loss of soil carbon back into the atmosphere.

N_2O emissions are associated with nitrogen management practices, and these emissions are approximately 265 times more harmful in causing warming than CO_2. Nitrogen is necessary for crop production, coming from either organic sources (manure or compost) or synthetic fertilizers. N_2O emissions to the atmosphere is related to fertilizer application. The Intergovernmental Panel on Climate Change (IPCC) estimates 1%of the fertilizer applied escapes into the atmosphere as N_2O (IPCC, 2006). This amount, however, is determined by the water content of the soil, with saturated soils showing the most considerable losses. Management of water and soil health practices that increase soil aggregation and soil water holding capacity can decrease N_2O losses to the atmosphere.

Strategies to Sequester Carbon or Reduce GHG Emissions in Cropland Agriculture

To assess the potential carbon sequestration and reductions in Weld County, values for a range of strategies were extracted from the Comet-Planner™ tool, available from USDA-NRCS. These estimates are based on CO_2 equivalents that place all GHGs on an equivalent basis to account for the differences in warming potential. This allows for comparison on an equal basis, and it is the form that carbon markets utilize for GHG strategies. The data extracted from the pre-generated values in the Comet tool are provided in a supplementary table at the end of this section and show values of CO_2 equivalents on a per acre basis. The estimates generated and shown in Table 3 are based on values derived for general conditions and do not represent a specific combination of practices, e.g., crop rotation sequences, or exact reductions in N fertilizer, and should only be considered as a planning value**.** To determine more exact values of C sequestration and reduction for Weld County would require a detailed assessment of the current tillage, fertilizer, and crop rotation practices along with the soils, water management, and topography for each field**.** This can be done through a use a combination of techniques linking crop growth models with satellite imagery and soil/topographic maps. There is one component in these estimates that is not accounted for in terms of avoidance, e.g., reducing tillage intensity to save fuel and generate carbon savings and/or reducing nitrogen fertilizer to decrease the carbon footprint for manufacture or distribution of fertilizer.

Exact values of carbon sequestration and reduction for Weld County could be calculated through a detailed of the current tillage, fertilizer, and crop rotation practices along with the soils, water management, and topography for each field. assessment

Results shown in Table 3 are separated by crops grown under irrigated and dryland conditions and represent the total for that crop with practices that would potentially be adopted by producers. These estimates assume that all cropped land do not currently employ these practices in their management suite and would provide only a potential estimate of carbon sequestration. Practices were selected to be realistic of the crop produced, e.g., in sugar beets it is unrealistic to convert to reduced tillage intensity, but cover crops and N management changes may be realistic practices; in dryland winter wheat, reduced tillage and N management may be feasible, while use of cover crops in a water limited environment may not be successful. Therefore, these results are illustrative because the final and realistic results will depend upon each individual producer's adoption of different practices. The values presented in Table 3 should not be considered to be additive because a combination of practices may not result in the same impact as the separate practices.

The greatest potential for carbon sequestration exists in the irrigated fields because the availability of soil water for crop growth is the major limitation to the amount of carbon sequestered into the soil. The critical pieces of information required to analyze the carbon sequestration potential include data about the typical crop rotation sequence, current tillage practices, and nitrogen management practices.

Observations have shown that reduced tillage increases carbon storage because CO_2 is not released from the soil and the root system of the previous crop (which is the source of carbon into the soil) is not disturbed (Dold et al, 2019). To achieve a thorough analysis of the carbon credit potential, several factors must be evaluated. For example, what is the crop rotation with the forages, sugar beets, and corn? What are the current tillage practices across the county? Is manure generated from the beef and dairy operations distributed back to the fields as a nutrient source? These questions would require a comprehensive evaluation of production practices in Weld County utilizing the steps proposed in an implementation strategy.

The results in Table 3 represent a view of the potential carbon pool for Weld County, Colorado. These are not insignificant totals in terms of a carbon market and demonstrate the value of considering the county as an aggregator of carbon into the marketplace. By reducing its GHG footprint and sequestering carbon into the soil, the agricultural sector has the potential to provide offsets (carbon credits) that benefit other sectors and the overall economy.

Table 3: Potential CO_2 sequestration from various practices in Weld County. (Colorado based on Comet Planner data). Values expressed as tonnes per year for all of the crop area in a specific crop and separated by irrigated and dryland cropping systems.

		Mitigation Strategy		
Crop	**Acres grown**	**Intensive tillage to no-till or strip-till** **Reduction factor (0.44 tonnes/year/acre)**	**Legume cover crop with 50% reduction in N** **Reduction factor (0.20 tonnes/year/acre)**	**Replace synthetic N with feedlot manure** **Reduction factor (0.13 tonnes/year/acre)**
Irrigated Crop Production		**Total tonnes/year**		
Forage	104,301	45,892	20,860	13,559
Corn, grain	89,223	39,258	17,845	11,599
Corn, silage	56,383	24,809	11,277	7,330
Winter Wheat	15,395	6,774	3,079	2,001
Sugar Beets	14,520	0	2,904	1,888
Vegetables	9,471	4,167	1,894	1,231
Dry Beans	8,102	3,565	1,620	1,053
Barley	5,812	2,557	1,162	756
Sunflower	1,408	620	282	183
Sorghum, Chop	1,291	568	258	168
Oats	116	51	23	15
	Total Reductions (tonnes/year)	**128,261**	**61,204**	**39,783**

			Mitigation Strategy	
		Reduction factor (0.25 tonnes/year/acre)	Reduction factor (0.1 tonnes/year/acre)	Reduction factor (0.02 tonnes/year/acre)
Dryland Crop Production			**Total tonnes/year**	
Winter Wheat	95,208	23,802	--	1,904
Forage	30,231	7,558	--	605
Corn, grain	16,528	4,132	--	331
Proso Millet	13,312	3,328	--	266
Corn, silage	9,587	2,397	--	192
Sunflower	2,284	571	--	46
Sorghum, grain	1,486	372	--	30
Dry Beans	973	243	--	19
Oats	930	233	--	19
Spring Wheat	501	125	--	10
Barley	470	118	--	9
Triticale	420	105	--	8
Sorghum, chop	328	82	--	7
	Total Reductions (tonnes/year)	**43,065**		**3,445**

Potential strategies for decreasing GHG emissions from croplands include:

1. Reduce the tillage intensity in the irrigated corn for grain and silage and introduce a legume cover crop after the corn is harvested to provide ground cover, place more carbon into the soil, and reduce the water evaporation from the soil surface. This would sequester carbon and reduce the nitrogen inputs because of the legume crop. There is an additional carbon benefit in terms of carbon avoidance because less fuel would be used in this crop production scenario.
2. Wheat grown primarily in irrigated conditions with reduced tillage coupled with improved nitrogen management will provide benefit for decreasing GHG emissions by sequestering carbon into the soil. If all of Weld County's irrigated crops went from intensive tillage to no-till, the state would have a reduction of approximately 128,261 mmt per year. However, non-irrigated conditions and reduced tillage coupled with improved nitrogen management will not provide a substantial benefit for decreasing GHG emissions because of the pre-existing conditions of reduced tillage.
3. Utilize improved nitrogen management practices in all irrigated crops by replacing synthetic nitrogen with feedlot manure. Reduction of nitrogen fertilizers or improved nitrogen use efficiency has a positive

impact on the N_2O emissions, along with an effect of reducing the carbon footprint of nitrogen in manufacture and distribution of nitrogen fertilizers.

4. Utilize cover crops after sugar beets to restore the carbon loss through the harvest operation and provide nitrogen through a legume system for the next crop.
5. Reduce tillage intensity in all dryland crops; improve nitrogen management by replacing synthetic nitrogen fertilizer with feedlot manure.

Section 3

Opportunities to Reduce GHG Emissions from Animal Agriculture in Colorado

This section aims to inform environmental and conservation practices associated with livestock production in Weld County. Managing the environment in and around farms, ranches, and feedlots has always been important to the county's livestock producers. For generations, their livelihood has depended on effective soil and water management. Our intent is to highlight practices and technologies that can help livestock producers further decrease the environmental footprint of their operations, primarily through the management of methane emissions from dairy and beef cattle and the manure they produce.

Profile of Weld County, Colorado Animal Agriculture

Any initiative to improve Weld County producers' environmental footprint requires an understanding of the role and importance of animal agriculture in the county. Approximately 75% of the county is devoted to agriculture (Weld County, n.d.)., and it is America's richest agricultural county east of the Rocky Mountains. More than 3,000 farms, ranches, and feedlots in Weld County create ~ $1.7 billion in annual market value (Weld County, n.d.).

Weld County's ideal climate, ready feed availability, and quality water help support many of Colorado's large cattle feedlots and the state's dairy industry. The market values of animal agriculture products in Weld County (based on the 2017 Agriculture Census - List of Reports and Publications, 2017 Census of Agriculture) are detailed in Table 4 below.

Table 4: Economic impact of animal agriculture in Weld County, Colorado.

Livestock, poultry, and products	$1,698,529,000
Cattle and calves	$1,057,898,000
Milk from cows	$452,839,000
Sheep, goats, wool, mohair, milk	$106,691,000
Poultry and eggs	$70,044,000
Other animals and animal products	$7,442,000
Horses, ponies, mules, burros, donkeys	$2,556,000
Hogs and pigs	$833,000
Aquaculture	$226,000

The county is also home to processing facilities that contribute to both the county and state's economic vitality, including food giant and beef processor JBS USA, which is the county's largest employer, supporting 4,590 full-time equivalent jobs. Weld is already the 21st largest dairy county in the nation, and the new Leprino dairy processing plant is anticipated to increase dairy production in Colorado in the coming years.

Review of Animal Agriculture Emissions Sources

The livestock sector also provides opportunities to reduce GHG emissions in Colorado. There are three main sources of farm livestock carbon emissions: farming practices needed for feed production, manure management, and enteric fermentation (Figure 3). Livestock producers have always adopted proven beneficial management practices and technologies in the areas of genetics, reproduction, and nutrition. As a result of these practices, the carbon intensity of beef and dairy products continues to steadily decrease over time. Moreover, when gauging environmental impact, estimates rarely factor in the climate benefit that comes from proper grazing management of range and pasture. Grass and forbs pull CO_2 from the atmosphere during photosynthesis and some of this carbon is sequestered into the soil via root mass and improves soil health.

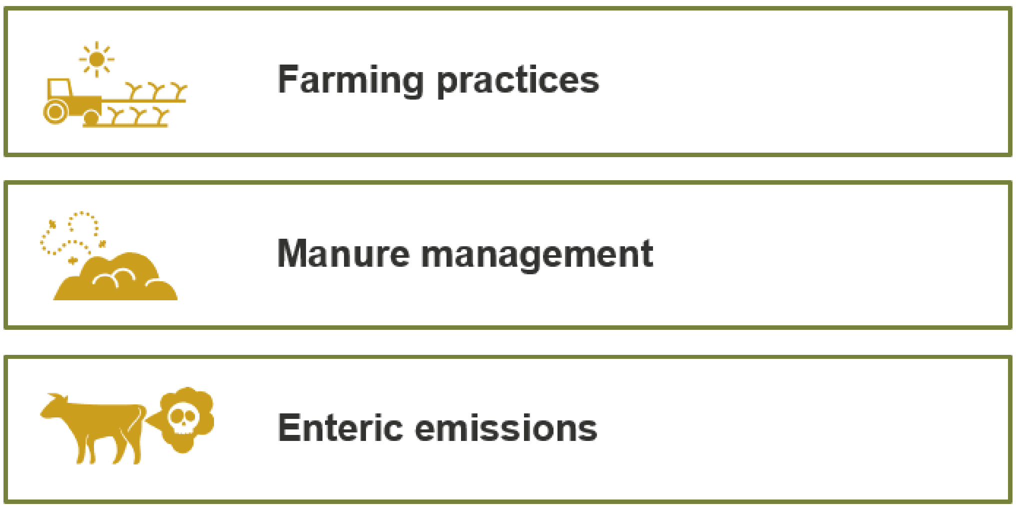
There are also more opportunities to reduce the emission of GHGs from livestock. At the national level, in August 2021, leadership in the beef cattle industry committed to be climate neutral by 2040 (Stewart, 2021) and leadership in the dairy industry committed to Net Zero GHG emissions by 2050 (Hershey, 2020). In coming years, both the National Cattlemen's Beef Association and Dairy Management Inc. will have programs, information, and tools for state associations and producers that will advance the climate-friendly production of beef and dairy in Colorado.

Among the three GHGs linked with agriculture production—CO_2, N_2O, and CH_4—methane is the dominant pollutant and thus the focus of this section of the report. (See Section 2 for more information about CO_2 and

N_2O.) Methane is a shorter-lived GHG than CO_2 but has 32 times the global warming potential of CO_2 (EPA 2021). According to the Global Methane Initiative (GMI) and many in the scientific community, methane is the second-most important GHG after carbon dioxide (CO_2). Research suggests that cattle are the leading agricultural source of GHGs globally, accounting for 14.5% of global emissions (UC Davis, 2020). In the U.S., however, cattle represent just 4% of all GHGs and beef cattle are responsible for just 2% of direct emissions due to improved production practices and technology (US EPA, 2016) .

Most methane emissions in U.S. animal agriculture are attributable to enteric fermentation from beef and dairy cattle and from the decomposition of manure in lagoons at some dairy farms and most hog farms.

Figure 3: Sources of on-farm livestock carbon emissions.



The Clarity and Leadership for Environmental Awareness and Research at UC Davis (CLEAR Center) published research in July 2020 outlining how biogenic methane (methane from cattle) differs from CO_2 emissions. Greenhouse gases -- such as carbon dioxide – are known as stock gases because they are cumulative each time they are emitted into the atmosphere, such as every time you drive your car to work. But when a gas such as methane – known as a flow gas – is emitted, it is stagnant and an equal amount of the gas is destroyed at the same rate that it is put into the atmosphere. For that reason, it is possible to reduce warming and other impacts to the climate by reducing the amount of methane produced. As one example, in 1950, there were approximately 22 million dairy cows in the United States (Blayney, 2002). Today, there are about 9 million dairy cows, and yet the United States produces the same amount of dairy products that it did with nearly 2.5 times fewer animals (Melgares, 2021).

The four distinguishing factors differentiating biogenic methane from CO_2 are:

- It stays in the atmosphere for about 12 years as opposed to 100 years.
- It is derived from atmospheric carbon, such as CO_2.
- It is part of the biogenic carbon cycle.

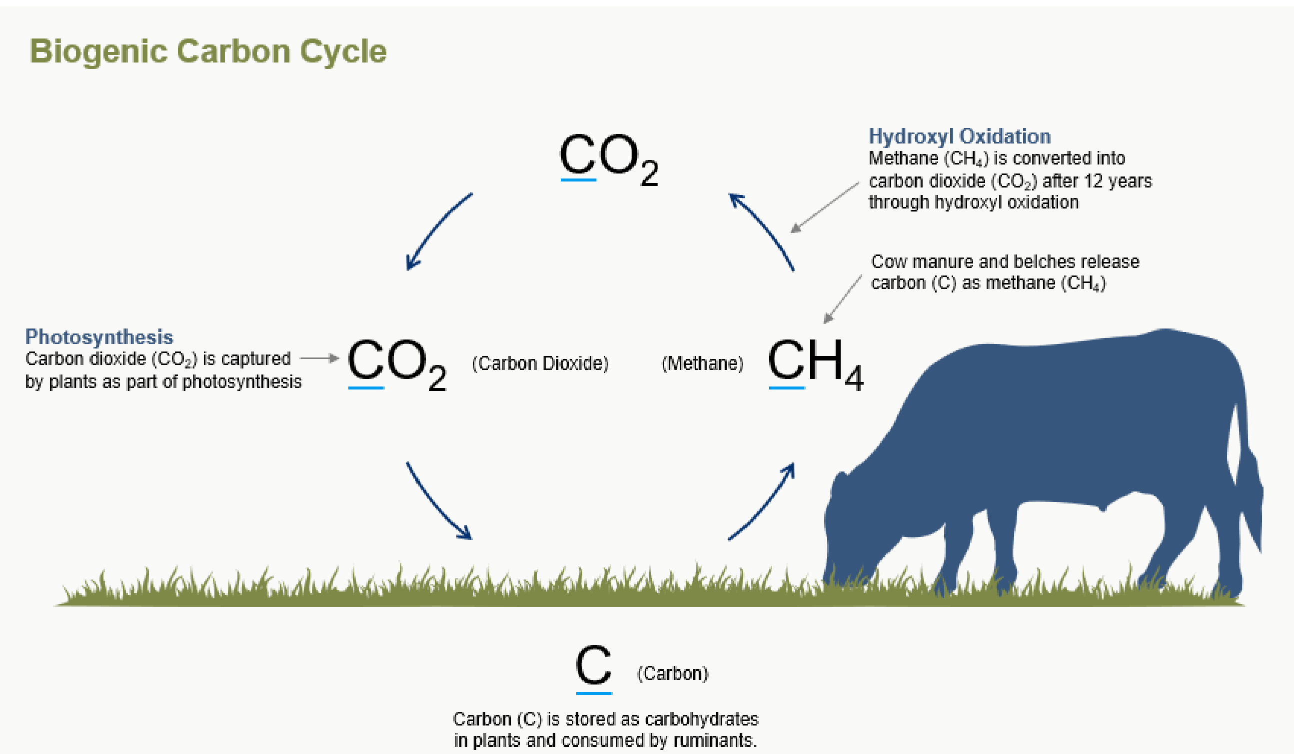
- It eventually returns to the atmosphere as CO_2, making it recycled carbon.

Research into reducing GHG emissions is increasingly a global endeavor, with research organizations like Land Grant Universities and animal health and nutrition companies advancing science and driving innovation.

Mitigation Strategies

Exploring methane mitigation strategies on livestock operations requires an understanding of activities and practices that control methane production inside the cow and those that control methane outside the cow, also known as the Biogenic Carbon Cycle (Figure 4). We will start with control inside the cow.

Figure 4: Biogenic carbon cycle. *Adapted from UC Davis, 2020.*



Inside the Cow: Livestock Emissions Reduction Interventions

While there are inherent differences between feed and dairy animal lifecycles, the three meaningful areas for interventions remain largely the same across both beef and dairy.

Several methane mitigation interventions focus on the reduction of enteric emissions caused by rumen fermentation. During fermentation, typically low-quality feedstuffs like grass, silage and hay are broken down in the rumen. During rumen fermentation, volatile fatty acids and ruminal bacterial protein are formed, in addition to free hydrogen (H+) ions. To cope with the free H+ ions, which could cause the rumen to become acidic, the biological process couples the free H+ ions with carbon to form methane (CH_4), which is then “burped” from the rumen, allowing the animal to digest these low-quality feedstuffs continually.

Several potential emissions reduction solutions currently being researched are discussed in this section.

Feed Additives and Supplements that Reduce Enteric Methane Emissions.

To date, there are no commercially available feed additives in the U.S. that have proven to be highly effective at reducing enteric emissions of methane. However, there is an enormous amount of research and development (R&D) going on across the globe to reduce enteric emissions and ultimately decrease the environmental footprint of beef and dairy products (Hiar, 2021; GRA, 2020; Zelp, 2020; Tricarico, 2021). It is important for the NWL Task Force to track and stay current on developments. Several feed additives are currently under R&D and could be available commercially in the near future.

Agolin, an essential oil, and Silvafeed, a plant extract, are two products that are commercially available and show promise of reducing enteric emissions of methane, though there is not yet enough scientific evidence that shows high efficacy. Bovaer or 3-NOP , is the one product that has been scientifically proven to reduce enteric emissions by at least 30% in over 30 trials conducted around the world (DMS, 2019). The widespread use of Bovaer could potentially cut methane emissions globally by up to 20 million metric tons per year (Hiar, 2021). Bovaer is an enzyme inhibitor (inhibits methanogenesis) and has been called Beano for cows by some because of the similar mode of action as the human product Beano. Bovaer has just received regulatory approval in Brazil and Chile for use in beef and dairy cattle. In the U.S., the Food and Drug Administration (FDA) Center for Veterinary Medicine has categorized Bovaer as a drug , which means a long and expensive path to regulatory approval and likely several more years until it is commercially available for use in the U.S**.** Once commercially available, widespread adoption of the product will likely require that beef or dairy retail brands pay for the producers in their supply chain to use it or the cost is offset by the sale of carbon credits generated or some other form of incentives.

Newtrient, in collaboration with the Innovation Center for U.S. Dairy, is an organization commissioned by dairy co-ops across the U.S. It has been working with leading experts, companies, and agencies to help dairy farmers reduce their environmental footprint through innovative solutions and manure management. Newtrient has been reviewing and compiling emerging research on feed additives in various stages of development. The latest status on what feed additives are available to reduce dairy enteric methane emissions, as summarized by Dr. Juan Tricarico in 2021, is included in Table 5.

Bovaer or 3-NOP , is the one product that has been scientifically proven to reduce enteric emissions by at least 30% (DMS, 2019).

A central question, however, is cost. It remains to be seen what entity(ies) in the beef and dairy value chains will pay for feed additives to be used to produce low carbon beef and dairy products if there is no performance improvement.

Table 5: Potential of feed additive solutions to reduce enteric emissions.

Additive	Answer	Main reason/considerations
Seaweed	No	Not available in commercial quantities. Conditions of use not yet established. Unknown animal, food, and environmental safety risks.
Lipids	Yes	Known risks on animal nutrition above maximum inclusion level. Limited mitigation in diets with high lipid content. Usually requires diet reformulation.
3NOP	No	Not registered. The manufacturer is pursuing approval through the New Animal Drug Application (NADA) process requiring Food and Drug Administration (FDA) review.
Tannins	Yes	Known risks on animal nutrition and health with increasing intake to achieve effective mitigation doses. Conditions of use not clearly established. Requires diet reformulation. Low confidence (wide range) on expected mitigation response.
Nitrate	Yes	Known risk on animal health with increasing intake from water, forages, and the additive to achieve effective doses. Risk of overfeeding can lead to animal death.
Agoln	Yes	Low confidence on expected mitigation response due to limited evidence on mode of action and efficacy.

Disclaimer: The information provided does not, and is not intended to, constitute legal advice; instead, it represents Juan Tricarico's opinions based on available evidence. Table adapted from Tricarico, 2021.

Vaccines and Genetic Selection

Vaccines can also be used to assist with enteric fermentation. A successful vaccine would trigger an animal's immune system to generate antibodies in saliva that suppress the growth of methane-producing microbes. A New Zealand milk co-op, Fonterra, in collaboration with the Pastoral Greenhouse Gas Research Consortium (PGgRc) is currently working on a vaccine solution to reduce enteric emissions (GRA, 2020).

In addition to vaccines, a potential for genetic selection centers around the ability to breed cows with better feed conversion abilities and subsequent lower enteric emissions (Pickering et al. 2015). Both vaccines and genetic selection are very much in the research stage and need to be tracked through time as the potential solutions continue with R&D.

Wearable Devices

Zelp is a methane-reduction device (analogous to a catalytic converter) that is mounted above the nose of the animal, using a halter. Zelp claims a 53% reduction in methane emissions (Zelp, 2020). The headgear recharges automatically and is designed to work for four years. Cargill recently announced a strategic partnership with Zelp. Even if this solution proves to be effective, the cost and logistical problems associated with its use at scale seem nearly insurmountable.

Outside the Cow: Manure Treatment and Carbon Sequestration

Manure Treatment

Manure treatment depends on the type of cattle operations. With beef cattle, there are no pressing issues regarding GHG emissions from manure. On cow/calf and stocker operations, the cattle are grazing and defecating on open range and pasture, and the manure breaks down naturally and feeds the soil.

With confined cattle operations, GHG emissions depend on the type of operation. In dry lot dairies and beef feed yards, the manure is handled dry because it is deposited on dirt and is periodically removed, stacked, and composted before being spread on cropland at agronomic rates for optimal crop growth. Methane emissions from dry manure decomposition are very low. For dairy cattle housed in free stall barns the manure is handled wet via flushing (using recycled lagoon water) or scraping of the manure, to what is usually an in-ground, lined, man-made pond known as a “lagoon.” Breakdown of the undigested feed in the manure produces methane that is emitted to the atmosphere from the lagoon.

The methane in biogas (typically 60 - 65% content) can be captured, scrubbed, injected, and sold as renewable natural gas (RNG) into the natural gas pipeline grid (Figure 5). Thanks to the federal Renewable Fuel Standard market mandated by the EPA for transportation fuels and some state mandates, RNG can generate tradable environmental benefits that are very valuable. As of March 2021, there are 52 manure-based AD systems producing RNG (includes pipeline injection and compressed natural gas (CNG) projects) in the United States with 44 RNG projects under construction.

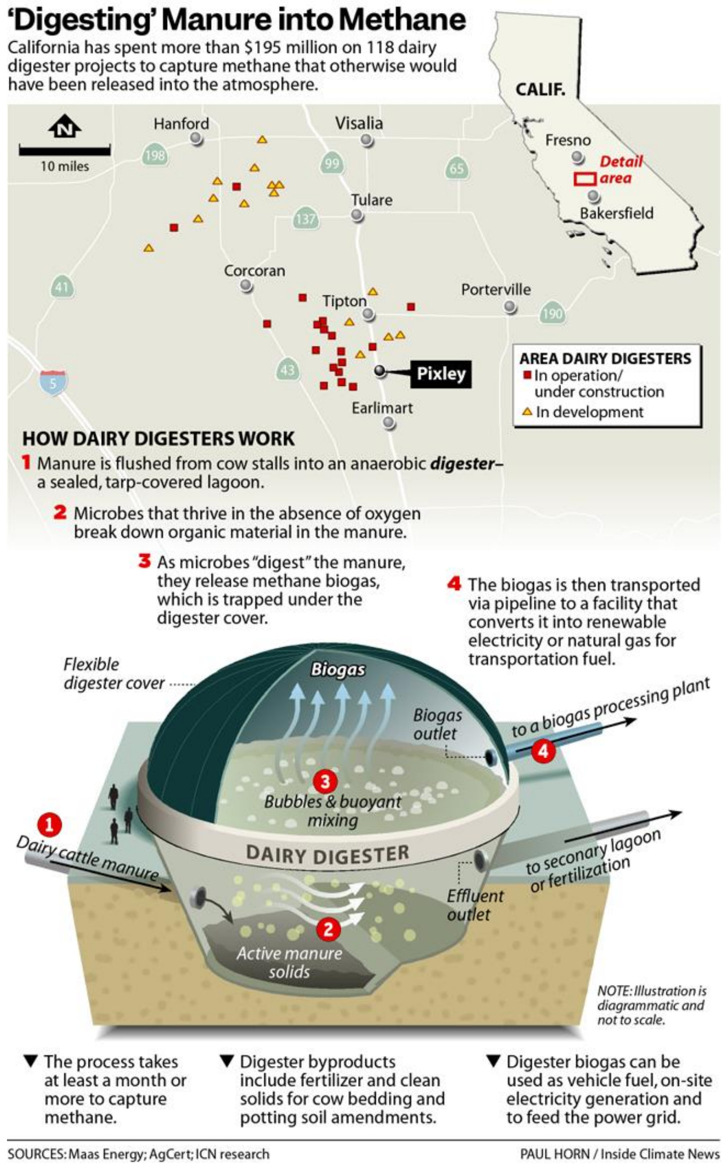
In 2020, ~273 AD projects operating at commercial livestock farms in the U.S. accounted for in AgSTAR’s Livestock Anaerobic Digester Database reduced 5.00 million metric tons of CO_2 equivalent ($MMTCO_2e$) including 4.17 $MMTCO_2e$ direct methane reductions and 0.82 $MMTCO_2e$ emissions avoided (EPA 2021a).

The sale of the environmental benefits from AD systems (known as Renewable Identification Numbers (RINs) and Low Carbon Fuel Standard (LCFS) credits) has incentivized the adoption of technologies on some farms from something as simple as a lagoon cover (used in warmer climates like California) to capture biogas to more sophisticated technology like heated and stirred ADs that use manure (and sometimes food waste and other byproducts) for feedstock. The biogas collected from covered lagoons and digesters can also be used to fuel generator sets or “gensets” that create electricity. However, with the advent of lower-cost solar- and wind-generated electricity satisfying the demand for renewable electricity created by and mandated by states’ Renewable Portfolio Standards for electric utilities, all new farm digester projects are making RNG a better return on investment (US EPA 2014). This could change in the future if biogas trade groups are successful in getting EPA to approve E-RINs, renewable electricity made from biogas used for charging electric vehicles.

ADs require a significant upfront investment. Historically, this proved to be a hurdle for dairy producers, however the California cap and trade system generated a revenue opportunity for private developers who are now seeking out large dairies for new AD sites. Weld County, Colorado should work to facilitate introductions between large dairies in the county that have an interest in pursuing an AD project and project developers and ensure the regulatory environment is attractive for new construction projects.

California is an interesting model for methane digestion, due in large part to the California Air Resources Board (CARB) and the implementation of the LCFS and funding for digester development (2017). The LCFS requires the use of cleaner low-carbon transportation fuels in California over time, and, therefore, reduces GHG emissions and decreases petroleum dependence in the transportation sector.

Figure 5. Digesting manure into methane.



Interestingly, with sufficient scale, some Weld County dairy farms can both reduce CO_2 equivalent emissions and generate RNG, RINs and LCFS credits because the RNG is theoretically "wheeled" to California because it is displacing conventional compressed natural gas (CNG) in the pipeline. Oregon has recently enacted an LCFS that may create more opportunities for Weld County dairy farmers to generate an additional revenue stream through the marketing and sales of RNG and associated environmental benefits (Oregon Clean Fuels Program).

Newtrient, in collaboration with the Innovation Center for U.S. Dairy, has reviewed and evaluated more than 250 technologies, including anaerobic digesters, commercially available for manure treatment in the dairy industry. See its technology catalog here. Technologies that aren't commonly in use on dairies are typically expensive to purchase and operate. Widespread implementation of technologies that further reduce the environmental footprint of dairies will require funding similar to the Alternative Manure Management Program in California that provided $32M to date to implement 114 on farm projects.

Carbon Sequestration

Several carbon sequestration practices are common in animal agriculture and are being promoted by universities and within livestock circles. They include **rotational grazing, perennial grasses, and avoided conversion of grasslands.** While total sequestration amount is dependent on many variables such as climate and soil moisture, one study in Brazil found that sustainable practices such as rotational grazing and pasture improvement produced 19% fewer emissions than farms that do not complete these practices (Bogaerts et al., 2017). This number dropped to ~35% fewer emission after farms completed more than two years of consistent sustainable practices (Bogaerts et al., 2017).

Rotational grazing is the practice of cycling animals to different parts of the grazing land on a regular cycle. Along with promoting soil carbon sequestration, rotational grazing encourages plants to develop more and deeper root systems, which has other environmental benefits. Rotational grazing also enhances soil fertility because roots continually decompose in the ground, boosting soil biomass and sequester carbon.

Perennial grasses are another common practice (planting of these grasses) that promotes soil carbon sequestration through reduced tillage, and plants with deeper roots promote water retention.

Common carbon sequestration practices in animal agriculture include rotational grazing, perennial grasses, and avoided conversion of grasslands.

Avoided conversion of grasslands is another way producers can avoid the loss of soil carbon, as well as other associated GHG emissions. Grassland and shrubland soils are significant reservoirs of organic carbon. When left uncultivated, soils can continue to store carbon belowground, support greater plant biomass, and avoid crop production practices (such as fertilizer application).

Three methodologies exist that producers can use to generate carbon credits and create revenue by NOT converting grasslands to crop production. The methodologies are: Verra, Climate Action Reserve, and American Carbon Registry. Registered projects have shown that avoided emissions, are from 1 – 2 tonnes/acre/year, depending on many factors such as soil type and precipitation.

Section 4

Potential for Weld County in the Carbon Market

Based on the agricultural demographics of Weld County, these are some potential opportunities:

1. Work with farm and livestock organizations in Weld County to evaluate production practices across the county in both grazed pasture and rangeland, irrigated and non-irrigated cropping systems, to determine the potential of carbon credits generated across the county.
2. Develop a program in which the county would act as an aggregator/broker into the carbon markets for producers within the county, presenting a pool of carbon credits of sufficient volume to enable a better contract than a single producer would be able to negotiate.
3. Develop an educational program for producers about the potential carbon credits generated and benefit of adoption of new practices on producers' economic returns.

Currently, the dynamics of ag carbon markets are being developed, and there is a large degree of uncertainty about the structure and requirements to participate in the programs offered by different groups. The exact amount of carbon credits depends upon the current adoption of practices by producers such as tillage, crop rotation, cover crops, and nitrogen management, as well as producers' willingness to change practices. There is an added advantage to carbon beyond the carbon market in terms of enhanced soil health, improved water and nitrogen use efficiency, and greater profitability from the farming enterprise. This value to the producer is not expressed in the carbon market but is a return directly to the producer.

Most carbon markets in the U.S. are voluntary except for the California Cap and Trade program. A non-regulated (GHG emissions) sector of the economy like agriculture can generate carbon credits, usually defined as a ton of CO_2 equivalents, by voluntarily reducing emissions or sequestering carbon in the soil through adoption of conservation practices or technologies. The carbon credits can then be made available to offset direct emissions from other sources in a carbon market. New agricultural carbon markets are modeled on adopting practices in the field beyond historical production practices when there is an additional benefit to carbon reduction over time. For example, a producer with a history of no-till or strip-till may not be eligible for a carbon credit but could become eligible with a new practice focused on nitrogen reduction strategies or by adding cover crops into the cropping system.

Recommendation: Explore opportunities beyond traditional carbon markets such as green bonds which are financial incentives that are earmarked to be used for climate and environmental projects.

Section 5

Recommendations for the Natural and Working Lands Task Force

Collaboration with stakeholder groups whose leaders in rural agricultural areas are embedded in local communities will be critical to the success of GHG emission reduction and carbon sequestration efforts in Colorado and specifically Weld County. We recommend that NWL Task Force members, Weld County officials, agricultural producers, and other stakeholders use the following engagement model going forward and engage with county and state farm and livestock organizations by meeting with them at their places of business.

1. SEEK TO UNDERSTAND – Listen, learn, and itemize the issues.
2. REFLECT WHAT WE HEAR – Share the itemized arguments back in a clear and concise manner focusing on key points:
   a. **Respect** for the role crop and livestock producers play in the economy and their communities and the significant regulatory systems they operate under.
   b. **Appreciation** for the great environmental stewardship that is in place (e.g., Nutrient Management Plans (NMPs), Certified NMPs, National Pollutant Discharge Elimination System permits for some operations).
   c. Recognition
      i. The critical role manure plays in soil health and its resulting positive impact on water quality.
      ii. The important work that Colorado crop and livestock producers do every day
3. SHARE THE VISION – Provide stakeholders with a clear and concise vision of what success looks like:
   a. Positive voluntary opportunities, not penalties – Focus on creating positive voluntary opportunities for farmers and livestock producers, not more burdensome regulations.
4. SEEK ALIGNMENT – Seek alignment on and support for a shared vision of policies that drive progress toward goals.

Below are some recommendations that can benefit Colorado agriculture while making progress on NWL goals:

1. Develop an economic model to determine the approximate annualized cost per ton of cropland and animal agriculture strategies and compare those to a benchmark value, i.e. carbon market price or a social cost of carbon or alternative projects.
2. Evaluate production practices in both irrigated and non-irrigated systems to quantify the potential for the generation of carbon credits across the county.
   a. Conduct surveys to determine the current level of adoption of practices using a combination of in-person surveys and satellite imagery.
   b. Incorporate data obtained from the surveys into an assessment that evaluates 1) the potential for carbon credits based on producers' production practices; and 2) the potential economic benefit of generating carbon credits to Explore the county and to producers.
3. Explore feasibility and develop programs to encourage the use of agricultural carbon markets within the confines of the State of Colorado mandates and restrictions
   a. Develop a program where county governments would act as an aggregator/broker into the ag carbon markets for producers within their county, presenting a pool of carbon credits of sufficient volume to enable a more favorable contract than a single producer would be able to negotiate.
   b. Explore different carbon registries to learn what is required for the development and verification of ag carbon credits within the county.
   c. Evaluate the resources, human and capital, required to implement a county-level scale aggregation of ag carbon credits.
   d. Determine the potential ag carbon credits within the county available for the ag carbon markets.
4. Develop a communication and education program for producers.
   a. Develop fact sheets on ag carbon markets for producers.
   b. Educate producers about the potential ag carbon credits generated and benefit of adoption of new practices on producers' economic returns.
   c. Conduct in-person seminars on production practices contributing to ag carbon reductions and the benefit to both the environment and producers.
   d. Assist producers in evaluating their current practices and strategies for adopting changes in management over time along with assistance in adaptive management programs yearly.
   e. Raise awareness thereby supporting enrollment in programs like the National Resource

Guiding Framework For Program Development And Strategic Alliances

5. Seek to understand
6. Reflect what we hear
   d) Respect
   e) Appreciation
   f) Recognition
7. Share the vision
   b) Positive voluntary opportunities, not penalties
8. Seek alignment

Conservation Service (NRCS) Environmental Quality Incentive Program (EQIP) that provides payments to farmers and ranchers for adopting practices that reduce their environmental footprint, often up to 75% of the practice cost. The community-based orientation of farms and farmers provides a great platform for Weld County.

5. Encourage the use of Anaerobic Digestors (AD) for manure management at dairy farms to assist in reducing CO_2 equivalent by commissioning an Anaerobic Digester Resource Guide to give Coloradoans a glimpse of the emerging RNG industry, as well as its many job opportunities and new markets for livestock generated environmental benefits.
6. Develop relationships with scientifically credible environmental nongovernmental organizations (NGOs), like the Environmental Defense Fund, for example. These organizations can help focus scientific resources to drive feed additive innovations that reduce enteric methane emissions. Collaborating with certain NGOs often provides the political and public-relations clout necessary to reach critical mass with non-agriculture audiences. It has become critical for farms and other food system entities to secure a social license (public endorsement) to operate, and these audiences play a large role in shaping public opinion on agriculture issues. As is the case in Colorado, many agricultural states also have large cities, and the heart of NGO support lies in those cities. Through alliances with NGOs that share a sensible GHG mitigation strategy with agriculture, Weld County can assist the State to develop a broad base of support that will help secure a social license to operate.

7. Collaborate with producers and counties to provide input and develop tools and practices to achieve GHG reductions
    a. Improve consultation with leading agriculture producing counties by forming a collaborative working group comprised of officials at both the State and local levels along with agricultural producers and academic researchers as CDPHE develops the desired GHG dashboard.
    b. Provide a forum for Weld County to provide input into CDPHE on the tools being used to measure and report on practices and technologies used to achieve GHG reductions and carbon sequestration.
8. Collaborate with other livestock important states and organizations and call on Congress and the Administration to either have FDA Center for Veterinary Medicine recategorize Bovaer as a feed additive instead of a drug or expedite the agencies review of Bovaer and other potential climate-focused products. This will allow for a product that is scientifically proven to reduce enteric emissions by at least 30% to be used immediately within animal agriculture.

A healthy agriculture sector means a healthy food system. As societal and business pressures increase for crop and livestock farmers in Weld County and across the country, it benefits all Coloradans to help create continued opportunities for agriculture to innovate, thrive, and produce in the most environmentally sound ways.

Resource Library

Additional information about topics in this paper can be found using the links below:

- 2017 Census of Agriculture
- A New Study on Regenerative Grazing Complicates Climate Optimism
- Agricultural Methane: Reducing Emissions, Advancing Recovery and Use Opportunities (globalmethane.org)
- Biden Announces Methane Reduction Effort, NCBA Confident In U.S. Cattle Record | Drovers
- California Department of Food and Agriculture Dairy Digester Research and Development Program – Program-Level Data
- Can California Reduce Dairy Methane Emissions Equitably? - Inside Climate News
- Carbon farming: reducing methane emissions from cattle using feed additives | Agriculture and Food
- Cargill and ZELP embark on strategic partnership to tackle methane emissions in the dairy industry
- Colorado | The Economic Contributions and Impacts of U.S. Food, Fiber, and Forest Industries (uada.edu)
- Comet Planner
- Cows and climate change: Making cattle more sustainable
- EPA AgSTAR Livestock Anaerobic Digester Database
- EPA AgSTAR Project Profiles
- Frontiers | Modeling of Greenhouse Gas Emission from Livestock | Environmental Science (frontiersin.org)
- Global Warming: How Does It Relate to Poultry? | UGA Cooperative Extension
- Grassland management impacts on soil carbon stocks: a new synthesis
- Iowa Anaerobic Digester Resource Guide
- Low Carbon Fuel Standard | California Air Resources Board
- NCBA announces Climate Neutrality Goal for Cattle Industry by 2040
- Net Zero Initiative Is Right Move For Dairy At Right Time
- New Zealand Agricultural Greenhouse Gas Research Centre
- Newtrient Technology Catalog
- Novel Feed Ingredient Bovaer® 3 NOP Enables Significant Reduction of Methane Emissions from Ruminanthttps://www.youtube.com/watch?v=bw6aLlqosLE
- Oregon Clean Fuels Program
- Right to Farm - Agriculture in Weld County – Weld County (weldgov.com)
- Summary of scientific research on how 3-NP effectively reduces enteric methane emissions from cows
- Understanding Global Warming Potentials
- Understanding soil carbon dynamics in pasture systems
- Why methane from cattle warms the climate differently than CO_2 from fossil fuels
- Zelp

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Appendix

Supplementary Table. Values of CO_2 change as a result of implementing management practices extracted from Comet Planner for Weld County, Colorado. Positive values show reduction in CO_2 while negative values indicate an increase in emissions.

Practices	CO_2 (tonnes CO_2 per year/acre)	N_2O (tonnes CO_2 per year/acre)	Total CO_2 impact
Residue and Tillage Management - No-Till (CPS 329) - Intensive Till to No Till or Strip Till on Irrigated Cropland	0.38	0.06	0.44
Residue and Tillage Management - No-Till (CPS 329) - Intensive Till to No Till or Strip Till on Non-Irrigated Cropland	0.24	0.01	0.25
Residue and Tillage Management - No-Till (CPS 329) - Reduced Till to No Till or Strip Till on Irrigated Cropland	0.28	0.05	0.33
Residue and Tillage Management - No-Till (CPS 329) - Reduced Till to No Till or Strip Till on Non-Irrigated Cropland	0.19	0.02	0.21
Cover Crop (CPS 340) - Add Non-Legume Seasonal Cover Crop (with 25% Fertilizer N Reduction) to Irrigated Cropland	0.16	-0.01	0.15
Cover Crop (CPS 340) - Add Non-Legume Seasonal Cover Crop (with 25% Fertilizer N Reduction) to Non-Irrigated Cropland	0.10	0.00	0.10
Cover Crop (CPS 340) - Add Legume Seasonal Cover Crop (with 50% Fertilizer N Reduction) to Irrigated Cropland	0.29	-0.09	0.20
Cover Crop (CPS 340) - Add Legume Seasonal Cover Crop (with 50% Fertilizer N Reduction) to Non-Irrigated Cropland	0.15	-0.05	0.10
Mulching (CPS 484) - Add Mulch to Croplands	0.21	0.00	0.21
Strip-cropping (CPS 585) - Add Perennial Cover Grown in Strips with Irrigated Annual Crops	0.11	0.05	0.11
Strip-cropping (CPS 585) - Add Perennial Cover Grown in Strips with Non-Irrigated Annual Crops	0.11	0.05	0.11
Nutrient Management (CPS 590) - Improved N Fertilizer Management on Irrigated Croplands - Reduce Fertilizer Application Rate by 15%	-0.04	0	-0.04
Nutrient Management (CPS 590) - Improved N Fertilizer Management on Non-Irrigated Croplands - Reduce Fertilizer Application Rate by 15%	-0.01	-0.03	-0.04
Nutrient Management (CPS 590) - Replace Synthetic N Fertilizer with Beef Feedlot Manure on Irrigated Croplands	0.21	-0.08	0.13
Nutrient Management (CPS 590) - Replace Synthetic N Fertilizer with Beef Feedlot Manure on Non-Irrigated Croplands	0.07	-0.05	0.02

Practices	CO_2 (tonnes CO_2 per year/acre)	N_2O (tonnes CO_2 per year/acre)	Total CO_2 impact
Nutrient Management (CPS 590) - Replace Synthetic N Fertilizer with Dairy Manure on Irrigated Croplands	0.21	-0.08	0.13
Nutrient Management (CPS 590) - Replace Synthetic N Fertilizer with Dairy Manure on Non-Irrigated Croplands	0.07	-0.05	0.02
Combination of CPS 329, 340 (legume) and 50% N fertilizer reduction in Irrigated Croplands	0.46	0.08	0.54
Combination of CPS 329, 340 (legume) and 50% N fertilizer reduction in Non-irrigated Croplands	0.33	0.05	0.38
Combination of CPS 329, 340 (non-legume) and 50% N fertilizer reduction in Irrigated Croplands	0.38	0.10	0.48
Combination of CPS 329, 340 (non-legume) and 50% N fertilizer reduction in Irrigated Croplands	0.26	0.06	0.32