Path to 2060: Decarbonizing the Agriculture Industry

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BATTEN REPORT

IMPROVING THE WORLD THROUGH ENTREPRENEURSHIP AND INNOVATION **AUG 2019**

PATH TO 2060:

Decarbonizing the Agriculture Industry

Innovation's Role in Sustainable Growth

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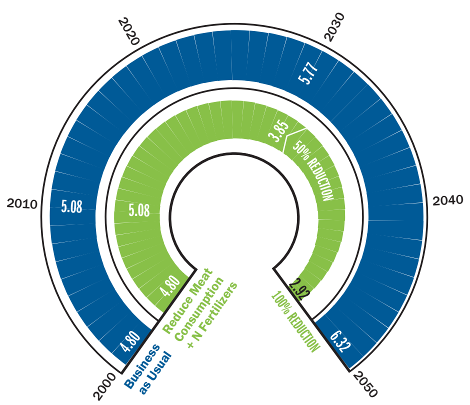
SNAPSHOT

Scientists say that global warming must be kept below two degrees Celsius to avoid significant global disruptions. Getting there will require near total ***decarbonization of all economic activity by 2060.***

Agriculture, forestry, and other land use represent ***24% of global greenhouse gas emissions.*** *Livestock and nitrogen fertilizers are key drivers of agriculture emissions.*

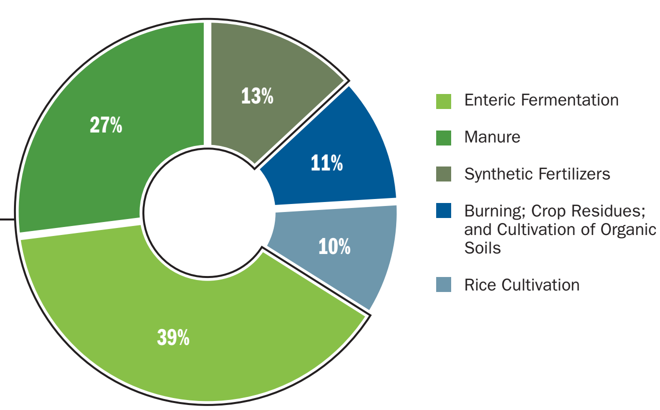
Decarbonization of agriculture will require significant innovation and shifts in behavior in the way we ***grow, distribute, and consume food.***

Meat and N Fertilizer-Free Scenario
Agriculture Emissions (Gtons/year)



NOTE: FAO 2030 and 2050 projections for ***enteric fermentation***, ***manure management***, & ***N fertilizer emissions*** reduced by 50% (2030) and 100% (2050). Decarbonizing these three sources would significantly reduce total agriculture emissions.

Global Agriculture Emissions
by Source (2016)



Source: FAOSTAT, Emission Data for Enteric Fermentation, Manure Management, and Synthetic Nitrogen Fertilizers.

Source: FAOSTAT, http://www.fao.org/faostat/en/#data/GT/visualize

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WHY 2060?

In the 2015 Paris climate agreement, 175 countries pledged to commit to greenhouse gas (GHG) emission reductions in order to limit global warming to no more than two degrees Celsius from preindustrial levels. According to the atmospheric scientists, achieving this goal requires limiting total cumulative global emissions to 2,900 gigatons of CO_2. Since the Industrial Revolution, global CO_2 emissions have reached 2,100 gigatons; this leaves a carbon "budget" of 800 gigatons. Assuming the continued emission of GHGs in the near future, staying within this carbon budget will require near-total decarbonization of global economic activity by 2060.[1]

The agriculture, forestry, and other land use (AFOLU) sector, as defined by the United Nations (UN) International Panel on Climate Change (IPCC), accounts for 24% of global GHG emissions, with agriculture representing the majority of them.[2]

In this report, we assess the potential for complete decarbonization of the agriculture industry by 2060.[3] We define decarbonization broadly to cover the reduction of methane (CH_4) and nitrous oxide (N_2O) emissions, which represent 22% of global GHGs[4] and 82% of total agriculture GHG emissions.[5] Livestock farming, which produces methane, and the use of nitrogen fertilizer, which produces nitrous oxide, represent the majority of global GHG emissions.

CH_4 and N_2O are potent GHGs. Global warming potential (GWP), which is the energy that a gas will absorb over a 100-year time frame relative to 1 ton of CO_2, is 28 for CH_4 and 265 for N_2O.[6] This means that CH_4 and N_2O are more potent than CO_2 even though they represent only a quarter of all gas emissions worldwide (CO_2 represents the remaining percentage at 76%).[7] While much of the public focus has been on CO_2 mitigation, addressing agriculture-driven CH_4 and N_2O emissions is critical to mitigating climate change.

Fortunately, there are opportunities in this sector to significantly reduce CH_4 and N_2O emissions. We focus our research on in situ GHG-emissions and two GHG-intensive sources, livestock farming and soil management.

UVA DARDEN'S BUSINESS INNOVATION AND CLIMATE CHANGE INITIATIVE

UVA Darden's Business Innovation and Climate Change Initiative facilitates dialogue across a diverse set of stakeholders from business, nonprofits, government, and academia about the role of innovation in addressing climate change. In support of this initiative, the Batten Institute for Entrepreneurship and Innovation is publishing a series of reports that explore technology innovation and the drivers behind the market disruptions needed to decarbonize our economy. These reports synthesize research of industry sectors that hold promise for innovation and significant reductions in carbon dioxide emissions, including transportation, energy, industrials, and agriculture.

Visit **www.darden.virginia.edu/innovation-climate/** to learn more about the *Business Innovation and Climate Change Initiative* and to hear a podcast discussing the findings of this report.

EXECUTIVE SUMMARY

IN THIS *PATH TO 2060* REPORT, we **(1)** review current industry practice, **(2)** identify decarbonization opportunities, **(3)** characterize the US and global markets, and **(4)** explore the clean technologies and innovations that offer disruptive potential. We then assess the levers that could determine the rate of clean technology adoption moving forward and conclude with some thoughts on the timing of decarbonization, as well as the accelerators and roadblocks to meeting the 2060 goal.

Research conducted for this report is based on publicly available literature, websites, and datasets; attendance at the 2019 World Agri-Tech and Animal AgTech Innovation Summits in San Francisco, CA; and discussions with industry experts.

PATH TO 2060 KEY FINDINGS:

Future State of the Agriculture Industry

- By 2050, global food production will need to increase by 49% in order to support the projected worldwide population.
- Agricultural methane (CH_4) and nitrous oxide (N_2O) emissions could increase as much as 60% by 2030 if no action is taken to mitigate climate change.

Livestock Farming and Mitigation Measures

- Livestock is the biggest source of agriculture emissions. CH_4 represents 50% of these emissions, driven largely by enteric fermentation and manure management. Beef and dairy cattle account for 60% of all livestock emissions.
- Approaches to decarbonizing livestock farming include: capturing the methane and producing bioenergy; adding seaweed and probiotics to animal diets; and breeding low-CH_4 cows.
- Plant-based alternatives and lab-grown meat have the potential to significantly disrupt the meat industry, but must first clear cost and taste barriers.

Soil Management and Mitigation Measures

- About 40% of the soil used for agriculture around the world is degraded. Excessive use of nitrogen fertilizer alone, partially to increase yields under these conditions, is responsible for 13% of global N_2O emissions.
- Best practices, such as cover crops and regenerative farming, help to reduce synthetic nitrogen inputs. Precision farming, including the use of drones, can monitor soil and plant health, ensuring that the right amount of nitrogen fertilizer is applied at the right rate and right time.
- Gene editing holds promise to turn commodity crops into nitrogen-fixing plants, and indoor vertical farms are gaining in popularity for their ability to go soil-less while ensuring food safety and meeting demand for local food.

Levers for Agriculture Decarbonization

- About one-third of food produced each year is lost or wasted. Properly storing and more effectively distributing food in developing countries while educating retailers and consumers in developed countries could avoid 8% of global GHG emissions attributed to waste.
- Levers for accelerating decarbonization include: greater consumer demand for sustainable alternatives; public-sector R&D investment and incentives for effective land management; brand influence over supply chains; expansion of carbon sinks; and the creation of a carbon trading market.
- Decarbonizing the agriculture sector by 2060 seems unlikely, given the complexity of stakeholders involved in the food production chain. It will require a globalized effort to change how we farm, distribute, and consume food.

THE CURRENT STATE OF AGRICULTURE

IN 2017, THE WORLD POPULATION reached nearly 7.6 billion people.[8] The UN predicts there will be 8.6 billion people by 2030 and 9.8 billion by 2050.[9] With this growth in population comes an increased demand for food. The UN Food and Agriculture Organization (FAO) estimates that by 2050, 49% more food will need to be produced compared to 2012 global production.[10] How will farming operations and distribution scale to effectively and sustainably meet these growing needs?

2.2 BILLION
MORE PEOPLE
LIVING ON EARTH BY 2050,

AND 49%
MORE FOOD
NEEDED TO FEED THE GLOBAL POPULATION.

Complicating matters is the fact that as developing countries grow in wealth, they tend to shift to more protein-rich diets. According to the Organisation for Economic Co-operation and Development's (OECD's) FAO Agricultural Outlook 2018–2027, rising per capita income in developing countries will drive demand for beef and dairy products.[11] Global expansion of livestock, particularly dairy and meat production, and the feed production to support this growth, leads to greater GHG emissions, as evidenced by CH_4 and N_2O emissions increasing 17% between 1990 and 2005, according to the IPCC.[12] Looking ahead, the IPCC warns that agricultural N_2O emissions could grow between 35% and 60% by 2030 due to increased fertilizer use and manure production. Livestock-sourced methane could rise 60% by 2030, if CH_4 emissions grow in proportion to projected increases in livestock numbers.[13]

No other industry is so directly impacted by climate change, which further complicates matters. Significant shifts in temperature, weather patterns, water accessibility, and pest populations put stress on agriculture production, which already faces challenges in feeding the global population. There are already signs of this happening in countries like Australia, where persistent hot and dry conditions have contributed to deterioration of pasture conditions, rising grain prices, and low water supplies. While other countries around the world are seeing increases in production year over year, estimates published by the US Department of Agriculture (USDA) suggest that Australian 2019 beef and veal production will be 20% lower than that in 2014.[14] Pockets of Australian livestock farming may never recover. In Queensland, where farmers were already battling years of drought, record-breaking rains flooded the region earlier this year, leaving 500,000 cattle dead in their wake.[15]

According to one study published in the Proceedings of the National Academy of Sciences, for every 1°C increase in global mean temperature, global yields of wheat, maize, rice, and soybeans would, on average, be reduced by 6.0%, 3.2%, 7.4%, and 3.1%, respectively.[16] Some regions could be hit harder than others. For example, the study suggests that in the United States, maize production could be reduced by more than 10% with a 1°C increase.[17]

On a positive note, the AFOLU sector is unique in that it includes carbon sinks that remove CO_2, primarily through forests. According to FAO, carbon sequestration offsets about 20% of agriculture emissions.[18] Net emissions from deforestation dropped 25% between 2000 and 2015 as a result of a slowdown in deforestation and more effective management.[19] Yet, forest degradation and tree cutting still represent between 10% and 11% of net global GHG emissions.[20] The protection, maintenance, and expansion of carbon sinks will be critical to reaching a carbon balance on the planet. We discuss the carbon sink opportunity later in this report, following the discussion on decarbonization options.

Agriculture is positioned to substantially impact the speed and trajectory of climate change, and to benefit directly from those efforts. Best practices and greater efficiencies will help decrease emissions, but to decarbonize by 2060, we need to think in drastically different ways about how we grow and consume food.

LIVESTOCK FARMING

THE TERM "LIVESTOCK" PRIMARILY refers to cattle or dairy cows, chickens, goats, pigs, horses, and sheep. Livestock farming represents 80% of agriculture land use, when accounting for pasture grazing and feed production.[21]

Domestication of animals dates back to early civilization. Cattle in particular were used to not only provide meat but to work on the farm. The principles behind livestock farming didn't change much until the late 1700s, when British agriculturalist Robert Bakewell introduced selective breeding, a discovery that would serve as an important first step toward today's scientific methods for controlling livestock quality and production. In the decades that followed, improved nutrition, disease-control measures, and genetic engineering have allowed livestock farming to keep up with global demand.

By the 1900s, expansion of railways and refrigeration technology in the United States opened up the distribution of agriculture products, shifting the industry to more centralized production at a commercial scale. This allowed for larger, manufactured meat production, making meat more available across the country. Beef and chicken consumption got a boost mid-century with the introduction of fast-food chains like McDonald's and Kentucky Fried Chicken.[22]

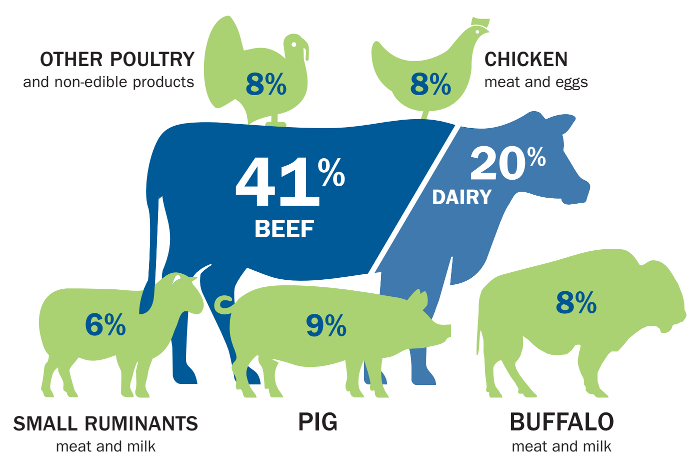
Yet, after peaking in the 1970s, per capita US beef consumption has dropped by one-third, while chicken consumption continues to grow.[23] Despite its more recent decline, beef continues to be a top choice on the American menu and is becoming more popular in developing countries that have a rising middle class and access to new wealth. The rise in chicken demand comes with its own environmental concerns, but with regards to land impact and carbon emissions, beef remains the worst offender. According to the World Resources Institute (WRI), beef production is 7 times more land- and GHG-intensive than chicken and 20 times more intensive than plant-based proteins.[24]

GREENHOUSE GAS EMISSION SOURCES

Methane represents the biggest source of livestock GHG emissions: FAO estimates 50%, with N_2O and CO_2 splitting the remaining 50%.[25] Manure management and enteric fermentation, defined later in this section, contribute more than half of these emissions.[26] Feed production to support livestock represents 41% of the remaining emissions, while energy consumption accounts for a small portion (5%).[27] Some of the solutions proposed for livestock management could also impact demand for feed production, potentially reducing emissions in those operations as well.

Several species contribute to livestock methane emissions, but cattle (beef and dairy) represent the largest share, at 60%, followed by pigs, chickens, buffalo, small ruminants, and other poultry.[28] Beef meat is the second most carbon-intensive (i.e., emissions per protein) livestock behind buffalo. Cattle milk is 70% less intensive than beef.[29]

Figure 1: Animal Methane Emission Sources



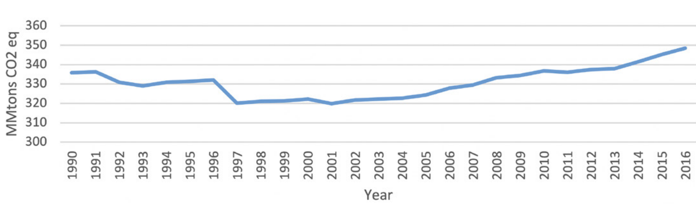
Source: FAO, By the numbers: GHG emissions by livestock, http://www.fao.org/news/story/en/item/197623/icode/

The storage of livestock manure emits methane, from anaerobic decomposition of organic matter, and N_2O through nitrification or denitrification.[30] N_2O is also released during manure soil application. The approach to managing manure on-site depends largely on farm size. Smaller farms tend to collect and spread solid manure daily or weekly while larger farms typically have sizable lagoons for long-term liquefied manure storage pending application to fields or off-site transport. Emissions tend to be higher from liquid treatment systems.[31] One analysis of dairy farms in Wisconsin showed that large farms deploying liquid storage are 2-to-3 times more GHG intensive (CO_2-eq/ton manure) than smaller farms managing solid manure.[32] The methane released during liquid storage represented 70% of larger farms' emissions.[33]

According to FAO, CO_2-equivalent emissions from manure management have been climbing since 2001 (Figure 2).

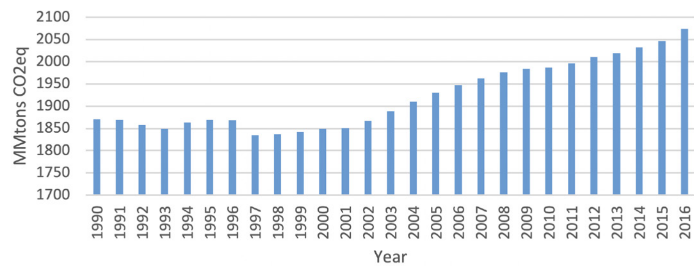
Enteric fermentation happens in the ruminant digestive track where plant material is digested, emitting methane in the process. The most common pathway for methane release is belching. Methane levels are closely tied to feed quality and composition, but also to breed. Cows typically eat a mixture of grass hay, alfalfa hay, and grains, as well as corn and grass silage (fermented pasture grass). The ratio of these food sources, as well as any vitamins and minerals added to the mix, impact digestion, and thus methane production. In addition to diet, recent scientific research suggests that there are genetic differences among cows that directly influence methane production.[34]

Figure 2: Manure Management Global Emissions



Source: FAOSTAT, Emissions-Agriculture, Manure Management

Figure 3: Enteric Fermentation Global Emissions



Source: FAOSTAT, Emissions-Agriculture, Enteric Fermentation

According to FAO, CO_2-equivalent emissions from enteric fermentation have been steadily rising since 2001 (Figure 3).

GLOBAL TRENDS

According to FAO, developing countries have experienced meat and milk consumption growth rates of 5.1% and 3.6%, respectively, between 1970 and 2007.[35] This growth was driven largely by East Asia, which saw consumption growth rates for these commodities reach close to 7% during the same time period. Overall, East Asia saw a sharp increase in per capita consumption (kg of commodity foods/year)[36] likely tied to expansion of the middle class and access to new wealth, and largely driven by a booming Chinese economy.

Growth has slowed in developed countries including the United States, yet the US continues to be the largest producer and consumer of livestock products, at 18% and 20% respectively. According to USDA, the United States, Brazil, the EU, and China represented a 60% share of both production and consumption in 2018.[37]

Looking to 2050, FAO predicts that growth in global meat consumption will slow due to slower projected population growth, more modest growth in per capita meat consumption (particularly in countries that were previously driving growth), the persistence of poverty, and cultural preferences against meat in some developing countries despite projected population increases (e.g., India).[38] Dairy, however, holds potential for significant growth in developing countries with per capita consumptions currently well below that in developed countries.[39] For example, FAO predicts that India will be a driver of growth in dairy consumption; today it accounts for 15% of world production, and this share could rise to more than 20% by 2050.[40]

Africa finds itself in a unique position, where significant growth is predicted for both production and consumption. Large increases in population—which could double by 2050 in some countries—urbanization, income growth, and shifts in diet will drive demand, and thus production.[41] FAO estimates that African demand for meat and milk will increase 261% and 399%, respectively, by 2050.[42]

To grow Africa's agricultural output will require significant investment in inputs and infrastructure. According to analysis by McKinsey and Company, eight times more fertilizer will be needed to support the growth, along with billions of dollars in irrigation, storage, and other infrastructure and government policies that improve distribution and trade.[43] Recognizing the importance of this region in ensuring food security, private- and public-sector investments are flowing into Africa.

Yet many of the African countries face challenges of undernourishment and food insecurity. Further, the impacts of climate change will be most greatly felt in more arid regions. Africa's ability to support increased demand will also depend on land and resource availability. According to the African Development Bank, these resources exist. Specifically, 400 million hectares of Savannah land could hold the key to increasing in-country production and reducing reliance on imports.[44] The Bank's Technologies for African Agricultural Transformation for the Savannahs (TAAT-S) initiative was developed in 2017 to cultivate just 16 million hectares of Savannah land for maize, soybean, and livestock production.[45] Organizations like FAO are partnering with USAID and several African governments to ensure sustainable development of the livestock market, including support for local communities.

Meat and dairy production and consumption growth rates will vary greatly depending on region, but overall, there will be an absolute global increase by 2050. Carbon emissions are tied to this growth and will continue to rise without innovative, mitigation measures.

OPTIONS TO DECARBONIZE

For livestock, the immediate solutions fall into two categories: methane capture/utilization and feed modification and digestive support. What if you could modify the cow itself or avoid eating it altogether and still get the protein needed for a balanced diet? Radical solutions are emerging, changing the very definition of a domestic cow, and if commercially scaled, these could drastically cut methane emissions around the world. Methane capture could offer a new renewable energy source to utilities, and thus a new revenue stream for farmers. In this section, we explore several emerging approaches toward livestock decarbonization.

Methane Capture and Bioenergy. For centuries, farmers have been storing manure to apply as fertilizer on feed-crop fields. As previously discussed, a significant amount of methane is released during the storage process, particularly in liquid form. According to EPA, the majority of manure emissions come from dairy and swine farms. Anaerobic digesters are closed systems that can be used to capture the biogas, using the methane as an energy source for heat or electricity. Adding other organic wastes, such as food and crop residues, can increase biogas production.[46] The biogas replaces otherwise piped utility-supplied natural gas. While the burning of it releases CO_2, it avoids the methane otherwise emitted from long-term manure storage. EPA estimates that as much as 85% of methane emissions could be eliminated with the use of digesters.[47]

However, only 248 farms are using digesters to date, and most of those are dairy operations.[48] The majority of these farms use the biogas for electricity generation or combined heat and power, where excess heat from the electricity generation is used to heat the digester or adjacent buildings.[49]

The EPA estimates that biogas recovery systems are viable options at more than 8,000 dairy and hog farms across the United States.[50] One of the barriers to broader adoption of digester technologies is cost. The profitability of a farm using a digester depends on its ability to recover initial capital costs and to establish a long-term revenue stream to cover operational costs. Several states have offered incentive programs with varying levels of success.[51]

To address the capital cost barrier, Virginia's Dominion Energy is partnering with Smithfield Foods, the largest pig and pork producer in the world, to pilot several biogas recovery and energy distribution projects in a new venture called Align Renewable Natural Gas. The farmers cap their lagoons and own the anaerobic digesters that then provide the methane gas to Dominion to process and distribute to consumers. In return, the farmers are provided a long-term contract with Dominion that ensures a revenue stream.[52]

Feed Additives and Probiotics. Feed additives can reduce the number of microorganisms responsible for methane production. The corn, soybean, and grass typically eaten by cows cause digestion challenges that lead to more emissions. Viable additives and supplements include natural substances, compounds, fats, and oils. Scientists at UC Davis are exploring the use of seaweed in cattle feed, and to date, have produced an almost 60% reduction in dairy cow methane emissions.[53] Testers of the milk produced from seaweed-fed cows indicated there was no difference in taste in the products.[54]

Other researchers are working on probiotics to reduce methane. One company, Bezoar Laboratories, is working on a probiotic that, when coupled with nitrate, decreases methane production by 50%.[55] The Paenibacillus fortis probiotic also increases productivity and reduces pathogens. Bezoar's founder received the Unilever Young Entrepreneurs Award in 2017 for the product.[56]

The key to the success of additives and supplements is that they address not just the methane problem but also productivity and the overall health of the cow. In fact, there seems to be a close relationship between these factors. According to FAO, improvements in productivity could result in a methane reduction of 30%.[57] Healthier, higher-producing dairy cows means a smaller herd is needed to meet demand.

Genetic Breeding. In Canada, scientists are working to improve feed efficiency and reduce methane emissions through selective breeding. In theory, it's not that much different than Blackwell's work in the late 1700s to choose and breed animals that are healthy and productive. Yet, this approach to breeding goes even further, down to the cellular level.

In 2009, the domestic cattle genome was sequenced,[58] providing scientists and farmers the opportunity to identify the most productive beef and dairy cattle in the herd, and breed based on desired traits. For Genome Canada, one of those traits is lower methane production. About 10,000 cows are currently being monitored for methane production, with scientists collecting genetic material to identify the markers associated with low methane production, in addition to overall health and productivity.

Other researchers are working to identify organisms found in the rumen (the first of two stomachs where initial digestion takes place with the help of bacteria and microrganisms) that produce methane and isolate the associated microbial genes for selective breeding to reduce emissions.[59] The hope is that through this selective breeding based on genome sequencing, farmers can cultivate more productive, low-GHG-gas herds.[60]

The goal of the Canadian genome project is to distribute the "environmentally responsible" genes more broadly, particularly in regions of the world that otherwise would not have access to this kind of research.[61] Global distribution of a patent-free technology would more quickly scale this solution, but even so, selective breeding takes time.

Clean Meat. Clean meat, in-vitro meat, cell-based meat, cultured meat—these are all identifiers being used by the food industry for a new alternative to conventional meat products. Clean meat is grown in a laboratory and is derived from a sample of animal cells that are replicated in a culture outside of the animal. In addition to zeroing out methane emissions from enteric fermentation and manure, moving meat production from pasture to laboratory opens up land for other types of farming or reforestation and quells concerns around animal welfare and antibiotic use. Perhaps not surprisingly, PETA has indicated support of clean meat.[62] Lastly, the laboratory process offers faster production times compared to the time it takes to breed and grow animals for slaughter.

The clean meat production process while complex, leverages knowledge gained from years of research in the medical field. However, translating technologies used for medical processes to support clean meat is a significant challenge. There are several steps to producing clean meat: establishing cell lines, growing cells in media, scaffolding to differentiate cell types and encourage an organized pattern of growth, and scaling growth in bioreactors.[63] Today, each of these stages requires significant and expensive research and development.

There are major challenges ahead, including price point and consumer acceptance. The first clean meat hamburger introduced in 2013 by Dr. Mark Post of Maastricht University came with a $330,000 price tag. Alternative meat products have been in supermarkets for years, but have focused on using plant substitutes. While the adventurous, sustainably minded foodie might embrace clean meat, the general population will likely be wary of food grown in a laboratory. As clean meat commercializes and scales, prices for product offerings should become more palatable to the average consumer. During an industry panel at the Animal AgTech Innovation Summit in March 2019, half of the representatives agreed that clean meat will reach cost parity with traditional beef within the next 10 years. Consumer perception about lab-grown meat may be the bigger barrier to broader adoption.

One of the primary concerns of consumers is the belief that laboratory-grown meat is not "natural."[64] A study conducted by Faunalytics in January 2018 found that 66% of consumers would try clean meat, with 40% willing to pay a premium for it, but only when presented with education and positive messaging around clean meat.[65] Results from the study suggest that focusing on portraying clean meat as natural may be a lost cause, and messages that focus on taste, animal welfare, and environmental benefits may do more to convince consumers.[66]

WHEN PRESENTED WITH EDUCATION AND POSITIVE MESSAGING AROUND CLEAN MEAT

60% OF CONSUMERS WOULD TRY CLEAN MEAT

WITH 40% WILLING TO PAY A PREMIUM

There is a lot of excitement today around clean meat. We are witnessing a growing number of start-ups in the meat industry, all of which are working to drive prices down and convince consumers that clean meat is just as good as, if not better than, conventional meat. Products range from beef to chicken to fish. Several start-ups are located in the United States, including: Memphis Meats, Finless Foods, Wild Type, BlueNalu, Mission Barns, New Age Meats, and Just Inc. Incumbent meat companies are also entering the alternative meat game. In January 2018, Tyson Foods announced its investment in Memphis Meats.

These new ventures are capitalizing on efforts by veggie-burger companies to change the way consumers view staples like beef burgers and the chicken nugget. Customer acceptance will be critical to the success of clean meat.

SOIL MANAGEMENT

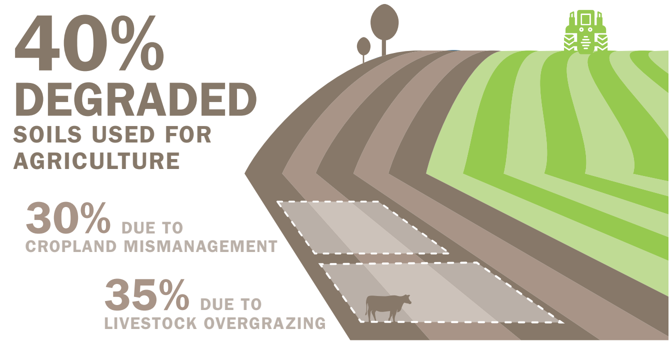
PLANT CULTIVATION BEGAN ABOUT 10,000 years ago, when humans left the nomadic hunter-gatherer lifestyle behind for one that provided more stable food sources in animal and crop farming. This is commonly known as the first agricultural revolution. Most researchers agree that agriculture largely originated in the Fertile Crescent, which included modern-day Iraq, Syria, Lebanon, Israel, and Jordan. New findings suggest that about 8,000 years ago, trade networks opened up between early farming communities and agriculture thus began to expand beyond the Fertile Crescent.[67]

The second agricultural revolution came in the 1800s, where mechanization of farming and the use of chemical fertilizers gave rise to large commercial farming operations and higher production.[68] Steel plows, grain elevators, and steam tractors were some of the new technologies introduced during this era, all of which focused on automation and efficiency.[69]

The third revolution came in the 1970s and 1980s and introduced the world to genetically modified organisms (GMOs), which also had the intent of increased production.[70] Today, the use of GMOs is wracked with controversy, and after centuries of farming that focused on over fertilizing and over cultivating to boost crop yield, the industry is beginning to realize the unintended consequence of soil degradation.

According to the Climate Opportunity Network, about 40% of soils used for agriculture activities around the world are degraded; 70% of topsoil critical to plant growth has vanished.[71] Soil degradation not only impacts field production but also reduces the amount of carbon stored, which further amplifies the impacts of climate change. According to FAO, soil degradation has released 78 billion tons of carbon into the atmosphere.[72] Livestock overgrazing is responsible for 35% of soil degradation, but almost 30% is due to agriculture activities, namely cropland mismanagement.[73]

Figure 4: Global Soil Degradation



Source: DNV GL AS, UN Global Impact, and Sustainability, Global Opportunity Report 2017, https://www.unglobalcompact.org/library/5081

Many industry experts and policymakers believe that we are in the advent of a fourth agricultural revolution; one that focuses on sustainable farm management and relies on digital technologies to achieve it.[74] Smart farm technologies being introduced today aim to maximize yields, while preserving soil health, and to reduce distribution inefficiencies. These technologies will not only help to ensure that production is able to scale to meet the rising demand for food, but could also drive down GHG emissions in the process.

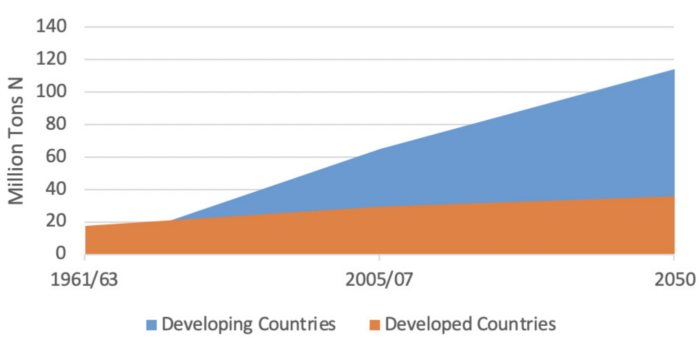
GREENHOUSE GAS EMISSION SOURCES

Soil acts as both a GHG emission source and a sink. In fact, soils hold more carbon than the atmosphere and all vegetation combined, second only to our oceans.[75] There are several factors that determine the carbon flux between the two. Biological drivers of soil emissions include microbial activity, root respiration, and chemical decay processes.[76] Flux rates are dependent on several factors, but the most influential are: humidity, temperature, nutrient availability, and pH value.[77] These factors can interplay with one another and they vary widely across the globe. In general, increasing soil temperatures, widely fluctuating moisture levels, and excessive nitrogen fertilizer application result in increased N_2O emissions.[78] As such, climate region (temperate, mediterranean, and sub-tropical), as well as farming practices, greatly influence soil emissions.

N_2O is produced by denitrification (removal of nitrogen) under anaerobic conditions. Soils naturally release N_2O into the atmosphere, but the addition of nitrogen-rich fertilizers greatly increases these emissions. Nitrogen is delivered through synthetic fertilizers, such as urea or anhydrous ammonia, or organic fertilizers, such as manure. Whatever is not used by the plant is devoured by microbes in the soil, combining it with oxygen and releasing N_2O into the atmosphere. Only about half of the nitrogen is taken in by the plant, while the other half is either tied up by microbes or released into the environment.[79] Some research suggests that the N_2O emission rate increases exponentially with increases in fertilizer rate.[80]

According to FAO, global nitrogen-rich fertilizer consumption has significantly increased since 1960 and is expected to continue to rise through 2050 (Figure 5).

Figure 5: Global Fertlizer Consumption: Historical and Projected



Source: FAO, World Agriculture Towards 2030/2050, Table 4.15 (2012 Revision).

Even more alarming is new data based on research conducted by the US Department of Energy's (DOE's) Lawrence Berkeley National Laboratory that suggests that carbon stored in deeper soil layers may be more sensitive to warming than previously believed. Calculations show that by 2100, deep-soil emissions could account for as much as 30% of human-caused annual emissions.[81] While much attention has been on topsoil, it appears that the problem could go much deeper.

GLOBAL TRENDS

According to FAO, growth in global annual crop production is expected to slow from 2.2% annually between 1961 and 2007 to 0.7% between 2030 and 2050, driven largely by reduced demand in developed countries and East Asia.[82] Despite slower growth, we will continue to see an absolute increase in demand and production as population grows overall. Production increases come from increasing yields as well as expanding the area of arable land available for crop cultivation.[83] By 2050, FAO estimates that global major crop production will increase by almost 40% and total harvested area will expand by 400 million hectares.[84] Yet, at the same time, FAO also estimates a nearly 30% increase in yields, or production per hectare of land, avoiding the need for further deforestation to create farmland.[85] This increase in yields will depend largely on continued investment and progress in agricultural research, particularly in those countries that are already maximizing current technologies.

Higher yields and crop intensities typically require higher rates of fertilizer. Over the last 50 years, nitrogen fertilizer was responsible for 40% of per capita food production increases.[86] In the early 1960s, 34 million tons of nutrients (including nitrogen, potassium, and phosphorous) were consumed for crop cultivation. By 2050, this number could increase to 263 million tons.[87] Developing countries are expected to represent 75% of fertilizer consumption.[88] As discussed in the livestock section, Africa is a region ripe with opportunity but is also most vulnerable to the effects of climate change.

According to FAO, world average per capita availability of food for human consumption reached 2,770 kcal/person/day by 2005/2007, which is well within nutritional guidelines.[89] Yet, there is global imbalance that needs to be addressed. About 500 million people are living in countries that average less than 2,000 kcal/person/day and another 1.9 billion are living in countries that average more than 3,000 kcal/person/day.[90] The challenge ahead will be reducing the carbon footprint of farming while finding ways to more efficiently grow and distribute food to meet the demands of expanding developing countries.

OPTIONS TO DECARBONIZE

Opportunities to reduce soil N_2O emissions lie in the timing, rate, and placement of nitrogen fertilizers, which can be controlled in part by best practices. Digital farming can provide greater precision. What if you could zero out N_2O emissions by avoiding the use of soil and nitrogen fertilizers? In this section, we take a look at the technologies and best practices that have the best potential for significant decarbonization.

Gene Editing of Crops. There is ongoing research in the area of gene editing to make crops more resilient to a changing climate. Perhaps the most successful and widely implemented is hybrid rice. Discovered by Chinese scientists in the 1970s, hybrid rice has helped to increase productivity and feed millions of people around the world. For example, in Nepal, where local rice yield was between 2.5 and 3.5 metric tons per hectare in 2001, hybrid rice raised this yield to 7.2 tons by 2014.[91] Hybrid rice has helped to feed a growing Chinese population, which accounts for 21% of the world's population, using only 7% of arable land.[92]

Crop resilience is critical for this sector, which faces significant losses in yield longer term with rising temperatures. While gene editing has in the past focused on resilience and increased yields, which also help to avoid acre expansion and the emissions that come with land conversion, there is also an opportunity for crops to mitigate N_2O emissions. For example, scientists are researching ways to design crops to make their own nitrogen, eliminating the need for nitrogen fertilizer.

Legumes such as soybeans and peas have long been revered for their natural ability to fix nitrogen through a symbiotic relationship with rhizobia bacteria. Fixation is the process in which bacteria turn N_2, an abundant gas in the atmosphere, into the more usable ammonia form, NH_3. The bacteria invade the root system and the plant provides nutrients that support the growth of nodules. Once matured, the nodules fix nitrogen, which is then supplied to the plant.[93] A limited amount of nitrogen fertilizer may be needed in the early growing period, but once established, the nodules are able to fix most of the plant's nitrogen needs; although this depends on the type of legume.

Could gene editing turn commodity crops like corn, wheat, and rice—responsible for a majority of nitrogen fertilizer use—into nitrogen fixers? The gene editing answer may not be in the plant itself, but rather in the bacteria. This is currently the focus of some exciting research and investment. One company, Pivot Bio, found that nitrogen-fixing bacteria existed on corn roots, but had gone dominant. Last year, the company launched the first microbial nitrogen-fixing solution into the US market. The product, which is essentially a liquid probiotic applied to the seeds, doesn't completely replace the need for fertilizer, but greatly reduces the amount needed.[94] Pivot is backed by large investors, including Bill Gates's Breakthrough Energy Ventures. Other companies are following Pivot's lead. In 2017, biotech multinational Beyer launched a joint venture with Ginkgo Bioworks to engineer bacteria that will help to create self-fertilizing crops.[95] Microbials have great potential, but their adoption will require significant investment and R&D along with farmer education.

Indoor Vertical Farming. Indoor vertical farms provide operators greater control over climate conditions, allowing for consistent, year-round harvests. Plants are stacked in towers, maximizing the yield per square footage of space. In some cases, yield estimates for vertical farms can be 30 times that of conventional farming.[96]

There are three types of growing systems: hydroponics, where water serves as the medium—often with the addition of soil-free options such as peat moss and coconut husks to provide structure; aquaponics, which is similar to hydroponics but with the addition of fish that provide nutrient-rich water to the plants; and aeroponics, where roots are suspended in the air and water mist and nutrients are applied directly.[97] Today, hydroponic systems are the least expensive and the most often deployed across all indoor farming operations.[98]

A combination of natural and artificial light is used to achieve the perfect level of light needed for growth. Vertical farms are protected from adverse weather conditions and pests within the building structure. This allows for farming without harmful pesticides. Water consumption is greatly reduced—some estimate as much as 95%[99] compared to conventional outdoor farms—as a result of capturing the moisture transpired by the plants and returning it to the system.

The crops most suitable for vertical farming are quick to turn—that is, they have a short time period between seed to maturity and market. These include lettuces, mustard and collard greens, basil, and mint.[100] Growers report that lettuces and microgreens offer the highest profit margins—as much as 40%—compared to other indoor-grown edible crops.[101]

INDOOR VERTICAL FARMS USE

95% LESS WATER

30x MORE PRODUCE

One important advantage of indoor farming is food safety. Growers are able to control every input into the growing process, including filtering the water used to irrigate the plants, which is often a source of E. coli breakouts across conventional lettuce farming.

Given their flexible indoor design, many vertical farms are being built in urban areas, which brings food closer to consumers, reducing transportation costs and associated CO_2 emissions from fossil-fueled transport. While there are some concerns around increased electricity use—energy is the largest operating cost with the lighting system, representing as much as 70% of the total[102]—growers are turning to more efficient LEDs to reduce lighting loads. The electrification of farming in general provides an opportunity for zero-carbon energy sources, like renewables, to fully decarbonize vertical farming.

A number of factors are driving the growth of vertical farming, including: global urbanization and consumer interest in locally sourced foods; extreme weather events and soil depletion; and demand for self-sufficiency, particularly in regions that do not have access to fertile land.[103] Yet even with this expected growth, vertical farming will represent a small portion of overall farming operations. Globally, vertical farms are expected to grow to 22 million square feet (500 acres) over the next five years.[104] Today, traditional outdoor farmland covers about 2.3 billion acres worldwide.[105]

Several challenges exist that threaten the accelerated adoption of vertical farms, all tied to cost. One barrier is the large capital expense needed to build the vertical farm. As many of these farms are positioned for urban markets, land and construction costs within cities can be steep. Profitability has been hard to prove over the years, with many vertical farms going out of business. Yet investments are being made—more than $500 million has been raised by the US urban vertical farming industry over the last couple of years.[106] Investment is coming largely from socially responsible funds looking to benefit from the local farm to table movement and invest in companies that offer sustainable practices and clean technologies.[107]

Another significant cost is labor. According to one survey, larger vertical farms (>10,000 ft2) employ 51 workers on average, which equates to 2.5 workers per acre cultivated.[108] In comparison, conventional farms in the US employ less than 1 worker per acre farmed.[109] Beanstalk Farms in Virginia, a UVA iLab alumni, is using machinery to automate more mundane tasks, reducing labor costs while offering the additional benefits of consistent high quality and safe produce due to less handling of the crops throughout the growing cycle.

Indoor vertical farms have promise, but face significant cost barriers that might be resolved with technologies that can automate more mundane operations. Growth will likely be concentrated in urban centers, providing a more sustainable substitute farming source for those populations, avoiding further farmland expansion, and substituting a small portion of traditional farming.

However, extending the technology to crops like corn and wheat will be a bigger challenge and is not currently the goal of market entrants.

To decarbonize global agriculture, we will also need widespread adoption of best practices and technologies, and significant advances in plant science, to drive down emissions created by conventional farming.

Best Practices. Regenerative agriculture is a holistic approach to farming, incorporating best practices that seek to enrich soils, improve watersheds, increase biodiversity, and support local farming communities. Increasing carbon stored in soils has the added benefit of higher yields and many best practices cost little for the farmer to implement.[110] For example, using cover crops between successive food crops can help to sequester CO_2 otherwise lost when fields are left bare. Also, managing the nutrients put into the soil, both in timing and substance, can have a significant impact on soil emissions. Of course, the effectiveness of these practices are highly dependent on soil and climatic conditions, which will vary based on region.

Conservation Tillage. No-till or reduced-till practices leave residue from last year's crop on top of the soil instead of being plowed under by tractors. Traditionally farmers plowed fields for weed control and to prepare soils for the next planting. Disrupting the soil releases carbon into the atmosphere. Advancements in weed control and planting equipment have provided farmers the opportunity to use no-till and reduced-till approaches, conserving topsoil, improving soil health, and reducing carbon emissions in the process.[111] However, emission reductions won't be realized unless these practices are paired with organic farming.

Cover Crops and Crop Rotation. Cover crops—those planted temporarily between main cash crop plantings—can extract excess nitrogen not used by the previous plants and help to sequester carbon. Retaining cover crop residue on fields can further increase the amount of carbon stored in the soil. Switching from a monoculture to polyculture rotation, or the planting of many different crops at the same time, can also increase carbon storage.[112]

Nutrient Management. Effective fertilizer application follows what's known in the industry as the 4 Rs: right source, right rate, right time, and right place. Fertilizer formulations can have a significant impact on N_2O emissions. One example is corn-soybean rotations, where emissions can be between two and four times higher using anhydrous ammonia than urea ammonium nitrate.[113] Additives can also reduce N_2O emissions—nitrification inhibitors can delay microbes' transformation of ammonium to nitrate closer to the time that plants are able to use it.[114] Slow-release formulations like polymer coatings might also reduce emissions.[115] More field studies are needed to measure the direct benefits of these approaches on reducing N_2O emissions. Determining the rate in which the fertilizer is applied so that it meets the needs of the plant and reducing the amount of available nitrogen in the soil will reduce N_2O emissions. Timing fertilizer application to the needs of the plant throughout the growing cycle will impact emissions. For example, applying it a few weeks after—instead of during or prior to—planting increases the likelihood of the nitrogen being picked up by the crop.[116] Finally, application close to the plant roots can ensure uptake.

Smart/Precision Farming. Introduced in the early 1800s, the Farmers' Almanac was a farmer's best source of predictive weather data. Today, the almanac is more novelty than guide, as farmers have access to more precise, regional short-term forecasts and predictive modeling tools. Climate-smart agriculture will rely on the farmer's ability to more precisely manage the health of crops with the help of data, in addition to monitoring weather conditions. By more precisely monitoring and addressing plant and soil health, farmers are able to reduce the amount of inputs needed to produce food. The big-data opportunity is opening up the door to technology companies that are investing in agriculture-specific digital solutions.

Sensors put directly in the soil can be effective at measuring soil health, informing the farmer of variability and problems. The sensors provide a soil map, which allows farmers to manage smaller tracts and pinpoint concerns. Once a problem is identified, soil samples are sent to a laboratory for more in-depth testing. However, there are some real-time solutions being introduced to the market by companies like AgroCares, which offers a handheld scanner that monitors soil fertility, providing data on important nutrients such as pH, nitrogen, and phosphorous.[117] Sensors can also monitor soil moisture, which allows the farmer to more efficiently irrigate different parts of the field depending on need. Monitoring and micromanaging soil nutrients and moisture across the field will result in a more productive and sustainable operation.

Drones are also being deployed to monitor crops and provide insight into plant and soil health, readiness for harvest, potential diseases, and pest infestations in real time. Farmers are able to more quickly and accurately assess every inch of their fields and stay ahead of problems that may impact production. In addition to data collection, some drones are equipped with the ability to spray crops. Able to scan the ground in flight, the drones hover at an ideal height, modulating spray as needed and avoiding drift, which results in less water and fertilizer/herbicides being used and faster spray times.[118] There is also talk in the industry of drones being able to drop seeds. But there are some challenges with drone deployment. Drones that come equipped with the image sensors and software needed for agriculture operations can cost tens of thousands of dollars, although one would expect that cost to decline with widespread adoption. FAA and local laws must also be met to operate a drone.[119]

Data is critical to climate-smart farming, but the volume of this data can be overwhelming to the farmer. Artificial intelligence (AI) can take large datasets and quickly perform analyses, suggesting a course of action based on predictive modeling that the farmer can then evaluate in real time. Based on industry discussions, AI is not quite ready for agriculture primarily because of the lack of consistency and comparability across data platforms. Managing and compiling many different types of data inputs in order to make farm-level decisions adds to the complexity. Collaboration between companies racing to provide data solutions, and even the creation of open-source software, will facilitate adoption of AI tools.

The success or failure of these digital solutions will depend first and foremost on whether they are easy to implement and understand, and whether they meet farmers' basic needs.

LEVERS FOR DECARBONIZATION

FOR DECARBONIZATION TO HAPPEN in the agriculture industry, levers need to be pulled throughout the entire food chain: production, distribution, and consumption. There is no silver-bullet technology, and the answer will likely be a mix of best practices, dietary shifts, and smart farming. It will also likely be regional, with different approaches identified based on country, farm size, and commodity.

The low-hanging fruit is education, yet this is no small task given how diffuse the agriculture marketplace is. According to FAO, 90% of farms around the world are managed by one person or a family, and these farms produce 80% of agricultural output.[120] Reaching these farmers will be critical to decarbonizing the industry. Agriculture extension organizations take information gained from science and research out to rural areas to educate farmers on the latest best practices and technology opportunities. These extensions are in place in both developed and developing countries, but there is often distrust in the information once it reaches the small farmer, particularly in developing countries. Organizations like FAO and WRI are working to put systems in place to support small farmers in these countries and build trust in science. The spread of mobile phones into rural areas is assisting with the dissemination of information to these farmers. According to FAO, mobile subscribers in low- and middle-income countries will reach 90% adoption by 2020.[121]

Private-sector initiatives, like that being spearheaded by the Gates Foundation, are also working to educate small farmers in developing countries. Major food companies are working in their own supply chains to educate their suppliers.

Yet to meet our 2060 goal, education must be coupled with adoption of new technologies and change in consumer demand. What are some of the other levers that can be pulled to accelerate this shift?

1. INCREASE CONSUMER DEMAND FOR SUSTAINABLE ALTERNATIVES

In this industry, the consumer drives change. There is a growing interest within more developed, industrialized food markets in local production and greater transparency into how food is sourced. Consumers are increasingly interested in the health of food: specifically, how it's managed and produced. This, in turn, is influencing how companies are farming soil and livestock. According to the National Restaurant Association's "What's Hot in 2019" survey of 650 chefs across the United States, top food trends for this year include: zero-waste cooking, locally sourced ingredients, and veggie-centric/vegetable-forward cuisine.[122]

The rise in consumer concerns related to animal welfare and the use of antibiotics has caused a seismic shift by big companies away from broader herd management and treatment toward more predictive medicine on an individual animal basis, with the help of AI and access to real-time data. Consumer interest has driven companies like Purdue to move toward 100% antibiotic-free production, and it will continue to push major brands to explore more sustainable alternatives to mainstream products.

In the United States, we have seen a sizeable shift away from dairy consumption to alternatives such as soy, almond, and coconut, due largely to consumer belief that plant-based products are healthier and better for the environment.[123] Overall milk consumption declined by 22% from 2000 to 2016, and alternative milks (plant-based) are predicted to represent 40% of US milk sales by 2021.[124] However, as mentioned earlier in this report, there will be a significant increase in milk consumption in developing countries that could more than balance out any declines seen in more developed countries.

Plant-based burgers have been available in stores for years, but they have been largely viewed as strictly a vegan alternative. Environmentally conscious flexitarians, or consumers that largely eat a vegetarian diet but consume meat occasionally, are looking for alternatives, but don't want to give up taste. Companies like Impossible Foods are introducing plant-based alternatives that serve as substitutes for meat lovers, competing with conventional beef patties on texture and taste. These alternatives are being picked up by national restaurant chains, which are able to more quickly reach customers across the country. After nearly a month of piloting an Impossible Whopper in St. Louis, Burger King already has plans to expand pilots to other parts of the country based on overwhelmingly positive consumer response and will make the product available to all stores nationwide by the end of the year.[125] If successful, other chain restaurants will likely follow its lead.

"Clean meat" will benefit from the path paved by the plant-based burger movement, changing consumer perception about the ingredients of a burger. However, there is still the challenge of consumer messaging and education. Being transparent about process, ingredients, and the benefits of clean meat will help to address concerns.

Ultimately, taste will drive greater acceptance of alternative proteins. If producers can get the balance of taste and price right then we should see greater uptake in more developed markets.

Consumer demand for sustainably sourced wood products can help to reduce deforestation and encourage growth of new forests and carbon sinks. International labeling programs such as the Forest Stewardship Council (FSC) and the Program for Endorsement of Forest Certification (PEFC) certify products that are produced from responsibly managed forests. These third-party organizations offer searchable databases of products and companies, and major retailers like The Home Depot carry certified products.

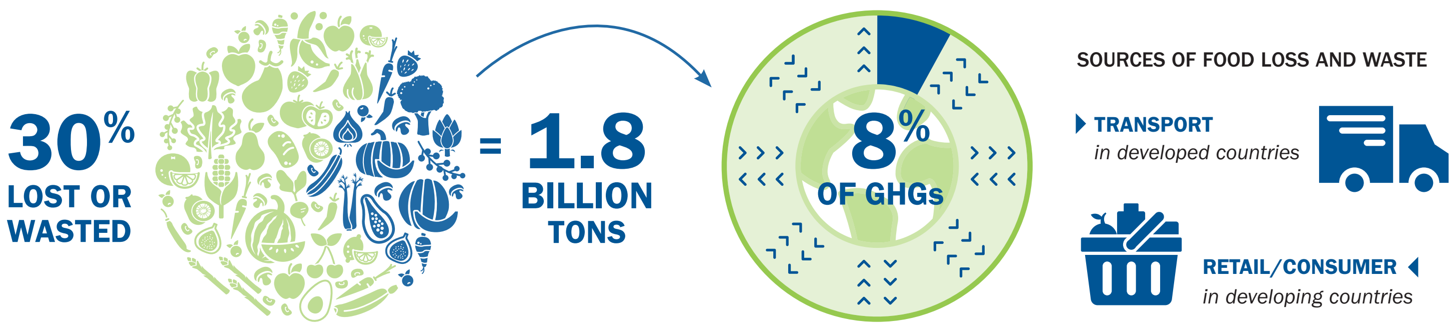
2. REDUCE FOOD LOSS AND WASTE

According to FAO, one-third of the food produced annually for human consumption is lost or wasted,[126] which equates to 1.3 billion tons of food.[127] FAO estimates that food waste represents 8% of global GHG emissions.[128] If food waste were a country, it would be the third-largest emitter.[129]

Where this loss or waste happens along the supply chain depends on global region. In developing countries, loss happens at the harvesting, storage, and cooling stages due to financial, managerial, and technical barriers.[130] Some estimates suggest that only 10% of perishable food is refrigerated.[131] Cold chain (i.e., refrigerated supply chain) storage and transportation could greatly reduce food waste in developing countries. One example provided in the book *Food Foolish* is India, which represents 28% of banana production, but exports less than 1% due to an incomplete cold chain system.[132] Smaller-scale, low-cost technologies that can be deployed in rural areas and policies that help to support their adoption could reduce carbon emissions otherwise attributed to overproduction of food to account for losses.

In developed countries, where infrastructure is in place to support the supply chain, waste occurs at the retail and consumer stages. In the United States, ReFED estimates that 52 million tons of food produced each year is sent to landfills. A lot of attention has been paid to efforts to save "ugly" food, attracting new ventures that buy imperfect fruits and vegetables from farmers and distribute directly to consumers. Yet, 85% of the waste actually happens at these later stages.[133]

FOOD WASTE IN DEVELOPING AND DEVELOPED COUNTRIES



ReFED evaluated 27 waste reduction actions that offer the potential to reduce 18 million tons of GHG emissions annually in the United States.[134] The three actions identified as the biggest contributors to this reduction if implemented include: centralized composting, waste tracking and analytics, and consumer education campaigns.[135]

Composting turns organic waste into humus, which can then be used to support healthy and fertile soil. Central composting facilities could be regionally located, working with multiple smaller community operations and providing the benefit of economies of scale, reducing the cost of the organic fertilizer that is then sold to the community. However, there are challenges. The capital costs for the facility and equipment can be prohibitive, low-cost synthetic fertilizers continue to benefit from cheap oil and industrial production, and food wastes need other carbon-rich sources to balance the nitrogen-rich compost.

Restaurants and retailers largely aren't aware of the amount of waste they are generating on-site. Auditing waste streams is the first step to identifying reduction opportunities. Solutions may include adjusting inventories, tracking sell-by dates, donating to food banks or livestock farms, and composting. All of these solutions carry their own carbon-reduction potential. Using software solutions to track food waste can be daunting and will require time and resources to implement.[136]

As with many environmental issues, consumers understand the food waste problem, but do not see themselves as part of the solution. According to FAO, North America is home to the most wasteful consumers on a per capita scale.[137] Interestingly, consumer education was also identified by ReFED as the top action with the most financial benefits to society, or economic value per ton. The challenge lies in the fact that food is relatively cheap in the United States and that behavior is hard to change unless the change is emotionally or financially motivated. National and local consumer education campaigns that engage public and private industry stakeholders with messaging that touches on those issues most important to the average American, including saving money, are critical.[138]

3. INCREASE PUBLIC-SECTOR INVESTMENT AND INCENTIVES

For decades, US farmers have relied on the Farm Bill to support them through tough growing seasons and to help stimulate demand for domestic crops. The bill was first drafted in 1933, at the time of the Great Depression, to address farmer needs and widespread poverty in the United States.[139] Farmers needed to produce to make a living while demand for their goods was declining. The federal government paid farmers to slow productions and bought surplus goods to help feed hungry people.

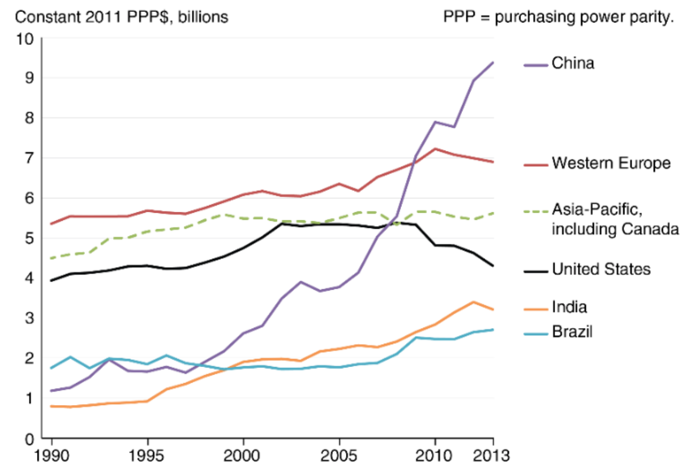
Every five years, the Farm Bill is reviewed by the federal government to ensure it adequately addresses the needs of farmers and Americans. Today, the majority of bill spending goes to nutrition, namely the Supplemental Nutrition Assistance Program (SNAP).[140] Other areas addressed include commodity crop revenue insurance, international trade support, guaranteed credit and loans, rural development, and natural disaster crop insurance.[141]

The most recent Farm Bill was signed into law on December 20, 2018. There are several parts of the bill that address soil and forest conservation, and more climate-friendly farming practices in general. For example, incentives are provided for best practices such as cover crops, crop rotation, and advanced grazing management, as well as comprehensive conservation planning.[142] There are also new research priorities around soil health and authorization of policies that support adapted seed varieties to navigate the effects of climate change.[143]

While the inclusion of conservation-focused incentives in the Farm Bill is promising, the fact is that US public funding for agriculture R&D has trended downward since 1970. Fortunately, private funding seems to be picking up where public investment has left off. According to USDA, public-sector funding of agriculture R&D began declining in 2003, and for the first time, private-sector investments surpassed those from government sources.[144] By 2013, federal and state government funding represented 23% of total US agriculture R&D investments, while the private sector and other nongovernmental sources (e.g., foundations and farmer organizations) represented 76%.[145] USDA's budget (where most of the federal government dollars are allocated) had fallen from $6 billion in 2003 to $3 billion.[146] While the FY2019 appropriation increased this slightly to $3.4 billion, the US White House Administration has proposed a cut in funding for FY2020 to $2.8 billion.[147]

Elsewhere in the world, public funding for agriculture R&D is increasing, led by China (Figure 6).[148] Chinese government investment in R&D increased almost eightfold between 1990 and 2013.[149] China is also investing in the modernization of Africa's agriculture industry, with President Xi pledging in 2016 to provide funding support to those efforts.[150] Chinese companies are expanding into new global markets through acquisitions of companies in more developed markets, such as the United States

Figure 6: Agriculture Public Sector Funding Across Key Global Players



Source: USDA, https://www.ers.usda.gov/amber-waves/2016/november/us-agricultural-rd-in-an-era-of-falling-public-funding/

and Europe, in an effort to get access to research expertise and more in-depth understanding of efficient production practices.[151] One example is the 2013 acquisition of Smithfield Foods in the United States by the WH Group. Private-sector R&D investment is also increasing in China, from 3% in 1995 to 16% in 2006 of total country expenditures on agriculture.[152]

Conservation programs are also being implemented in other parts of the world. The EU requires member states to allocate 30% of income support to greening activities, providing direct payment to farmers that adopt best practices that preserve natural resources.[153] More recently, the EU Commissioner announced the pursuit of the Farm Carbon Forest Initiative, which would reward farmers and forest managers for practices that sequestered carbon.

Government policy can serve as a barrier to new technologies and practices. For example, plant gene editing requires no additional regulatory approvals if scientists stay within breed. It's a different story for livestock, which is regulated like a pharmaceutical drug. While countries like Brazil and Argentina allow gene editing of animals within the same genetic code, similar to plants, the EU and United States treat gene editing like a

According to Ceres, of the **50 TOP FOOD AND BEVERAGE COMPANIES** *that sell consumer goods in the United States and Canada,*

ONLY 15 ARE REPORTING EMISSIONS FROM **UPSTREAM AGRICULTURE**

For those companies, SCOPE 3 EMISSIONS ACCOUNTED FOR **86% OF TOTAL REPORTED EMISSIONS**

GMO, requiring additional approvals. Yet the very definition of gene editing is different than that of a GMO, with the former referring to edits made within the same genome and the latter defined as introducing foreign DNA into the sequence. Even within the seemingly more supportive plant gene editing world, there are differences in regulations depending on country. For example, the genetically edited hybrid Golden Rice was recently approved for commercial sale in the United States, but although it was created and patented in China, cannot be sold in country due to stricter regulations. Regulations for gene editing activities are crucial to ensuring food safety, but movement toward internationally recognized standards that protect public health while allowing for innovation and scientific advances could accelerate the shift to more climate-friendly and resilient food sources.

4. LEVERAGE THE SUPPLY CHAIN

For many food companies, the majority of carbon emissions comes from their supply chains, otherwise known as Scope 3 emissions. Influencing and tracking those emissions can prove difficult for even the biggest brands accustomed to wielding their purchasing power. These companies are in the best position to influence change in these channels, but many are not measuring or disclosing supply chain emissions. According to Ceres, a non-profit organization that works to build the business case for sustainability, of the 50 top food and beverage companies that sell consumer goods in the United States and Canada, only 15 are reporting emissions from upstream agriculture.[154] For those companies, Scope 3 emissions accounted for a surprising 86% of total company-reported emissions.[155]

Emission accounting protocols and tools are critical to company efforts to track GHGs and identify opportunities for reduction throughout the supply chain. Global organizations like Ceres are developing resources such as standards, methodologies, and calculators[156] for evaluating emissions from upstream agriculture operations and land-use change activities. Standardizing methodologies and protocols can help suppliers to consistently report performance across multiple customers.

Even when emission sources can be identified and measured, influencing multiple suppliers and distributors—particularly in other countries, each with their own regulatory requirements—can be challenging. To give a sense of the size of such a challenge, last year, Unilever mapped and released information on the 1,600 mills and 100 refineries that provide palm oil to their suppliers, most of which are located in Southeast Asia and South America.[157] The increasing popularity of palm oil—almost 50% of packaged products for sale at supermarkets use it[158]—is blamed for deforestation increases in countries with high species diversity and dense forests. To work with these international governments to achieve meaningful action requires in-country expertise and established relationships.

Some corporations are partnering with ag-science companies that have farmer networks already established to source sustainably grown inputs. Earlier this year, Anheuser-Busch and Indigo Agriculture announced a partnership to supply the beer company with 2.2 million bushels of Indigo RiceTM. According to Indigo, growers contracting with Indigo to produce rice for Anheuser-Busch will reduce water and nitrogen used by 10%, which will result in a 10% reduction in GHG emissions.[159]

These company-led commitments are encouraging, but to shift supply chains, there is strength in numbers. Multibrand partnerships with nonprofits and other stakeholders have proven effective at influencing change within a given input supply chain. Palm oil serves as a good example, where the nonprofit Roundtable on Sustainable Palm Oil (RSPO), brought together producers, consumer goods companies, retailers, traders, and NGOs to develop internationally recognized standards for sustainable palm oil. RSPO member companies also commit to implementing the standards. Some of these companies are sourcing 100% sustainable palm oil, including: Walmart, Unilever, McDonald's, General Mills, Hershey, General Mills, Mars, and Kraft Heinz.[160] According to RSPO, 19% of the palm oil produced globally has been RSPO-certified.[161]

Another example of multistakeholder influence is the partnership between nonprofits Carbon Undergraound and Green America and corporate advocates, Ben and Jerry's, DanoneWave, Annie's, and Megafood to develop a global standard for food grown from regenerative farming.[162] The Soil Carbon Initiative, developed with the help of 150 farmers, scientists, and other stakeholders, is seeking public comments prior to an end-of-the-year launch of the standards.[163]

Multistakeholder partnerships like these can help to accelerate the creation and adoption of the global standards needed to more quickly decarbonize food supply chains.

5. INCREASE CARBON SINKS

Carbon sequestration currently offsets about 20% of global agriculture emissions. Increasing our carbon sinks while working to mitigate agriculture emissions could lead to a significant reduction in our global carbon footprint. The good news is that options are already at our disposal, many of which are being implemented in developed countries. The Nature Conservancy recently released a study that claims that nature-based solutions are readily available and can get us a third of the way to Paris Agreement targets by 2030, with a tenth of that attributed to US action.[164] Mitigation pathways range from reforestation, forest management, and fire management to grazing optimization, cover crops, and alley cropping (the planting of trees alongside rows of crops).[165] Many of these pathways would require low cost to implement.

However, forests, once considered the biggest carbon sink opportunity and hope for carbon balance, could actually contribute to climate change if atmospheric warming continues. One study published by Harvard suggests that at some point, forests may emit more carbon than they sequester. Scientists warmed forest soils over the span of 20 years and measured not just one pulse of CO2, but subsequent releases that suggested an evolution of the microbes exposed to the warming temperatures, accelerating the rate of emissions.[166] Another study suggests that the world's tropical forests are actually acting as a net source due less to deforestation and more to reductions in carbon density within standing forests from degradation or disturbance—scientists calculated almost 70% of losses attributed to existing forests.[167]

Our best hope at mitigating GHG emissions might actually be through growth of new forests. A study released by the Birmingham Institute of Forest Research suggests that younger forests may better sequester carbon than old-growth forests like tropical rainforests. Researchers found that more than half of the global carbon sink represented by forests is found in middle- and high-latitude forests less than 140 years old. One theory is that reforested land is open and sunny, allowing newly planted fast-growing species to sequester carbon and incorporate it into their biomass quickly, while old-growth trees must compete for resources with neighboring trees in close proximity.[168]

Another hopeful carbon sequester is emerging: hemp. An inherently resilient and sustainable crop, hemp is low maintenance—requiring less water, pesticides, and fertilizer than corn—and offers a list of uses from livestock feed to textiles. Hemp grows vigorously, can be grown in fields otherwise retired from farming, and can also be used as a cover crop with the benefit of replenishing soils. According to some estimates, hemp can sequester 1.63 tons of CO_2 per ton grown.[169] Banned in the 1950s due to concerns around marijuana, many states have introduced new legislation that supports hemp cultivation. More recently, the 2018 Farm Bill officially lifted the ban on hemp. The US hemp market has already seen significant growth—in 2016, Americans bought $600 million in products, and by 2018, this increased to $1 billion—and with the federal ban lifted, growth is expected to continue to climb; one estimate suggests $2.6 billion by 2022.[170]

We are in the early stages of researching and truly understanding the benefits of land-use change and the long-term effects of warming on these sinks. The carbon sequestered will be a finite amount, and any work to expand carbon sinks must be coupled with continued declines in deforestation and reductions in emissions from agriculture operations.

6. CREATE A MARKET FOR CARBON

For agriculture, there is value in carbon sequestration in terms of soil productivity, but in addition to higher yields, what if farmers were also paid for the carbon? The idea of "carbon farming" is getting some attention, particularly in cap and trade markets. In 2015, the California Air Resources Board approved the inclusion of rice farmers in the state-wide cap and trade market, allowing for the generation and sale of carbon offsets based on a protocol of land-management best practices.[171]

Before any trading could begin, the carbon-reduction methodology had to be approved by the American Carbon Registry—a nonprofit that sets standards for carbon offsets—and the State of California. For rice, best practices around water management and drainage can result in reduced methane emissions.[172] In 2017, Microsoft purchased the first-ever carbon credits from US rice farmers.[173]

Additional protocols are being developed, led by non-profits like the Environmental Defense Fund (EDF). More recently, the American Carbon Registry approved a grassland management protocol.[174] New research suggests that grasslands may be better carbon sinks than forests, able to retain carbon even during wildfire events.[175] Yet, 1.6 million acres of grasslands aged 20 years or older were converted to croplands between 2008 and 2012.[176] The first carbon credits for grasslands sold last year, also to Microsoft.[177]

Although many countries have developed carbon-trading schemes, agriculture is not often listed as a participating industry. This is an area of great promise and opportunity, yet much work needs to be done to establish protocols and build the necessary infrastructure to support such a program.

AGRICULTURE DECARBONIZATION NOT LIKELY BY 2060

THE AGRICULTURE SECTOR IS A CRITICAL and complex one when it comes to decarbonization by 2060. At roughly a quarter of all global greenhouse emissions, the sector must see significant reductions in order to achieve the Paris targets. This will not be easy—demand for food will only increase as the worldwide population and demand for protein-rich foods by developing countries increase.

Unlike the transportation and energy sectors, there are no obvious emerging technologies, such as electric vehicles and renewable energy, that seem poised to radically disrupt the status quo. Rather, a sustainable transformation will likely require a combination of the diffusion of best practices, changes in consumer preferences, and the emergence of a portfolio of novel solutions that leverage technology to lower the agricultural carbon footprint. All of this will have to happen in a global industry made up of millions of enterprises, from large multinationals to small family farmers.

A viable path to 2060 seems unlikely, yet no other sector is as critical to human survival than agriculture. Decarbonization will likely necessitate a worldwide effort led by individual nation-states to create significant incentives and programs to dramatically change agricultural practices at the local level. Such a wholesale change seems daunting and unrealistic within this time frame. Despite the exciting efforts in the biotech and digital agtech segments, the prospects for a technological silver bullet seem very dim indeed.

We choose optimism, however. Agriculture is one of the few sectors with a high potential to serve as a carbon sink. Improved land-management practices and the conversion of lands to forests and other carbon sinks could greatly offset agricultural emissions. Only if we pursue all the levers available to us can we achieve decarbonization by 2060.

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KEY INDUSTRY RESOURCES

FOOD AND AGRICULTURE ORGANIZATION (FAO) OF THE UNITED NATIONS

FAO is an agency of the United Nations that leads a number of initiatives aimed at reducing worldwide hunger, malnutrition, and poverty. As part of its strategic priorities, FAO is working with countries to mitigate climate change and strengthen the resilience of agriculture systems around the world.
For more information: **http://www.fao.org/climate-change/en**

UN INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

IPCC is a body of the United Nations charged with assessing the scientific basis of climate change, identifying its impacts and future risks, and presenting mitigation and adaptation options. IPCC is best known for its synthesis reports on climate change. The most recent fifth assessment report (AR5), published in 2014, represents the most extensively researched and reviewed report released to date and serves as the basis for climate policy-making around the world.
For more information: **https://www.ipcc.ch**

US DEPARTMENT OF AGRICULTURE (USDA)

USDA oversees 29 government agencies managing programs in support of the following mission areas: farm production and conservation; food, nutrition, and consumer services; food safety; marketing and regulatory programs; natural resources and environment; research, education, and economics; rural development; and trade and foreign agricultural affairs.
For more information: **www.usda.gov**

US ENVIRONMENTAL PROTECTION AGENCY (EPA)

EPA's overall mission is to protect human health and the environment. Each year, EPA publishes the Inventory of U.S. Greenhouse Gas Emissions and Sinks that estimates total GHG emissions and removals associated with human activities, including major industry sectors like agriculture. This report is a collaboration across several US federal agencies, including USDA, and compiled by EPA to comply with commitments made under the United Nations Framework Convention on Climate Change (UNFCCC).
For more information: **www.epa.gov**

WORLD AGRI-TECH AND ANIMAL AGTECH INNOVATION SUMMIT PROGRAMS, MARCH 18–20, 2019

World Agri-Tech and Animal Agtech Innovation Summits bring together 1000+ companies, investors, start-ups, and other industry experts twice a year who are dedicated to advancing sustainable agriculture.
For more information: **https://worldagritechusa.com**

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