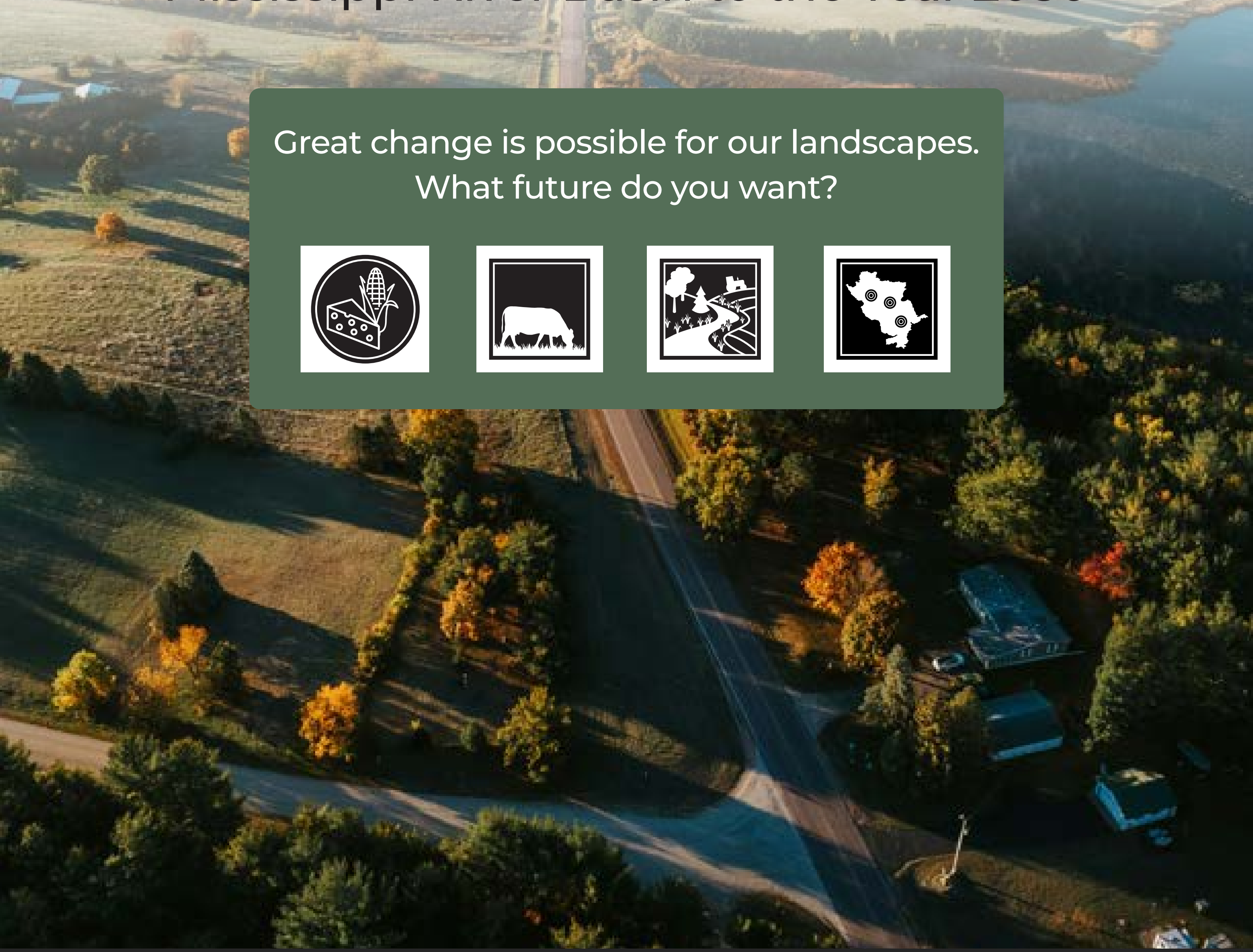
FEWscapes Scenarios

Aspirational Pathways for Food, Energy, Water, and Ecosystem Security in the Upper Mississippi River Basin to the Year 2050



Great change is possible for our landscapes. What future do you want?

FEWscapes
FOOD ENERGY WATER

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About FEWscapes

FEWscapes was a project led by scientists and educators at the University of Wisconsin–Madison to advance knowledge and support decision-making for food, energy, water, and ecosystem security in the Upper Mississippi River Basin. The project combined ecosystem modeling, policy and social research, and community engagement to discover new insights and inform regional policy and management. These scenarios were a main deliverable of the project. The project began in 2019 and ended in 2026. Learn more at fewscapes.wisc.edu.

FEWscapes Scenarios Research and Outreach Team

Eric Booth
Project scientist, UW–Madison Department of Plant and Agroecosystem Sciences

Kelsie Ferin
Project scientist, UW–Madison Department of Plant and Agroecosystem Sciences

Christopher Kucharik
Principal investigator, professor, UW–Madison Department of Plant and Agroecosystem Sciences and Nelson Institute for Environmental Studies

Christopher Lewis
Science communication graduate assistant and PhD student, UW–Madison Nelson Institute for Environmental Studies

Jenny Seifert
Watershed outreach specialist, UW–Madison Division of Extension

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Contents

Executive Summary

The ultimate purpose of the FEWscapes scenarios is to help illuminate what landscape changes may be necessary to achieve ambitious goals for food, energy, water, and ecosystem security in the Upper Mississippi River Basin *simultaneously*. That last word is central to this inquiry. Although food, energy, water, and ecosystems are interconnected, policies and programs designed to support these systems are often not. Sustaining these systems, particularly in a changing climate, may require more holistic management.

The FEWscapes scenarios are a set of four hypothetical pathways for landscape change in the Basin to the year 2050. Each consists of a narrative describing one pathway and a set of projected future outcomes, or model results, for food production, biofuel production, water quality, and ecosystem quality, which are based on the changes that occur in the narrative. Since the scenarios are aspirational, each narrative explores potential causes and consequences of land-use solutions for nutrient runoff in the Basin. Together, the scenarios are intended to highlight promising opportunities and potential threats to achieving future targets for food, energy, water, and ecosystems.

A research team at the University of Wisconsin–Madison developed the scenarios in partnership with agriculture and natural resources practitioners from across the Upper Mississippi River Basin. Through a technique called "backcasting," they identified future food, energy, water, and ecosystem goals the scenarios could aim for and potential solutions for achieving those goals. The goals were based on existing targets for food production, low-carbon energy production, water quality, and land conservation that had been established by U.S. federal government agencies at the time of this research. The four resulting scenarios reflect syntheses of the practitioners' ideas.

The Scenarios

Cropland Conservation

In 2050, almost all agriculture is conservation agriculture.

America's Pasture

In 2050, more than half of all farmland is grazing land.

Restoration Agriculture

In 2050, farmers tend not just crops, but also restored forests, wetlands, and prairies.

Hotspots for Transformation

In 2050, a mix of conservation agriculture practices, restored ecosystems, and perennial grazing land are strategically placed to maximize environmental benefit.

Two overarching implications of the FEWscapes scenarios are that (1) while some changes can happen fast, ecosystem responses to those changes can happen much more slowly; and (2) achieving goals for food, energy, water, and ecosystems is going to require transformative land-use change. None of the scenarios fully reaches the targets for food, energy, water, and ecosystems. These results demonstrate that planning for a future based on today's status quo will be inadequate.

Other implications include the following:

- Water quality improvements will take a long time, even despite transformational changes to land use, due to legacy phosphorus and nitrogen in the system.
- Dietary choices at the societal level will ultimately dictate whether food production goals can be achieved.
- Sustaining biofuel production will limit how much progress can be made toward goals for improving water quality, food production, and biodiversity.
- There are many solutions for improving habitats into the future, regardless of future climate.

Overall, our results indicate that decision-makers and practitioners may need to consider even more profound transformations than the ambitious scenarios we developed.

Introduction

Why and How the Scenarios Were Developed

Imagine a future with clean rivers and lakes, resilient and thriving farms, and biodiverse ecosystems. How could we get there? And is it possible to have it all?

The FEWscapes scenarios attempt to help answer these big questions. They are four different aspirational visions for landscape change in the Upper Mississippi River Basin, a five-state portion of North America’s largest watershed that includes parts of Minnesota, Wisconsin, Iowa, Illinois, and Missouri. By exploring how land use and climate change could impact food, energy, water, and ecosystem security to the year 2050, the scenarios are intended to help advance knowledge and support decision-making today.

Scenarios are explorations of “what if.” They are hypothetical storylines that play out plausible, contrasting trajectories of current trends and events into the future and incorporate real-world data to reveal possible future outcomes. Scenarios matter because trying to understand possible futures can help us make better decisions today.

A team of researchers from the University of Wisconsin–Madison, with outreach support from UW–Madison Division of Extension’s Natural Resources Institute, developed the FEWscapes scenarios in collaboration with a diverse set of agriculture and natural resources practitioners from the Basin. The research team facilitated discussions with these practitioners to identify goals, stressors, innovations, and opportunities that were worth exploring in the scenarios.

Since the scenarios are aspirational, they needed future targets for food, energy, water, and ecosystems as end goals to try to achieve. With support from the practitioners, the research team used the following recognizable targets established by U.S. federal government agencies at the time of the research.

Food production: Increase agricultural production by 40% by 2050, a target proposed by the U.S. Department of Agriculture.

Biofuel production: Achieve net zero carbon emissions by 2050, a target set by the presidential administration at the time.*

Water quality: Reduce nutrient loss in the Mississippi River Basin by 45% by 2035, a target set by the U.S. Environmental Protection Agency.

Ecosystem health: Conserve at least 30% of land by 2030, a target set by the presidential administration at the time.

**Note: The project focused specifically on biofuel production for energy, given its land-use implications and the capabilities of the models used.*

Importantly, a central question FEWscapes scenarios explore is whether and how these goals can be achieved *simultaneously*. Although food, energy, water, and ecosystems are interconnected, policies and programs designed to support these systems are often not. Sustaining these systems together, particularly in a changing climate, may require more holistic management.

Through a technique called “backcasting,” the researchers and practitioners sketched out different pathways the scenarios could take to achieve the goals. Backcasting starts by setting a desired future and then looking back to assess how to reach that end goal. The practitioners were challenged with identifying changes in land use and society that would be necessary to reach the goals simultaneously. The researchers then converted their ideas into four short narratives, each one a scenario that could plausibly achieve the goals.

The research team then used models to simulate the land use and climate changes that occur in the four narratives to understand how closely each scenario gets to the goals. The modeling process started with building a baseline from which the four pathways diverge. The research team used historical land-use data and computer models to generate baseline conditions that reflect how previous land use has influenced soil conditions, nutrients, and vegetation across the Basin.

To project future conditions, the research team quantified model inputs, a measurable set of landscape and climate conditions the models used to simulate how the four scenario narratives would impact land use and land cover change by 2050. The inputs included metrics related to land use, nutrient application, cropland management, and more. The research team also chose six commonly used future climate projections under which to evaluate each scenario. See appendices for more details about the model inputs.

With these model inputs, the research team used a suite of process-based agroecosystem and hydrologic models to estimate the consequences of the climate, land use, and social changes that occur in the scenarios between now and 2050. The primary models were Agro-IBIS and THMB. Agro-IBIS simulates agricultural ecosystems—from natural vegetation to managed cropland—while THMB simulates how nutrients and water flow across the landscape. As a pair, Agro-IBIS and THMB can estimate the future state of variables such as crop production, water quality and quantity, and flood regulation. Furthermore, to estimate total food and biofuel production in each scenario, the team used a separate model calculation based on assumptions about how crops are used in each scenario (i.e., for food, feed, or fuel).

The model results include projected future conditions for food production, biofuel energy production, nitrogen and phosphorus runoff, sediment loss, drought and flood frequency, perennial biomass, and ecosystem carbon storage under multiple projected future climates. They provide insight into how much progress the changes that occur in each scenario could make toward long-term goals for food, energy, water, and ecosystems in the Basin.

Ultimately, the scenarios can help shine light on potential pathways to achieving goals for food, energy, water, and ecosystems. Their intent is to spark transformative thinking about how to achieve these goals and, generally, help managers, practitioners, and policymakers prepare for a future that will be different from today.

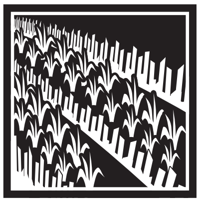
Join this conversation by exploring the scenarios and model results in this report or the **FEWscapes website**.

The Scenarios

Focusing on landscape and climate change, the four scenarios offer different pathways for achieving ambitious goals for food, energy, water, and ecosystems in the Upper Mississippi River Basin to the year 2050. The pathways represent different land-use solutions for addressing nutrient and soil loss.

Each scenario consists of a narrative describing one pathway and model results that project that pathway's future conditions for food, bioenergy, water, and ecosystems.

As you step into the four imagined futures, we invite you to find one idea that inspires you to work toward a future you want.



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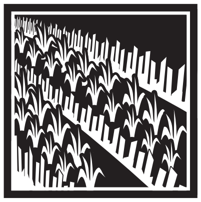
NARRATIVE

Cropland Conservation



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By 2050, many observers of American agriculture describe the 21st Century as “the age of the conservation farmer.” Intensive row crop production continues in a manner similar to preceding decades.

Now, though, the typical American field is host to a portfolio of practices designed to buffer its impacts on the surrounding landscape. Rye, vetch, clover, and other cover crops are ubiquitous. Nutrient runoff passes through saturated buffers before leaving most fields. Conventional tillage is rare.

The transformation began decades prior, emerging from a changing economic and political landscape.

Changes in global aviation drive a shift in biofuel production

In the late 2020s, nutrient management planning and cover crop use start to edge upward among Midwestern row crop farmers, spurred by dramatic changes in markets for biofuel feedstock. It begins in 2023, when the European Union (EU) establishes its Carbon Border Adjustment Mechanism, a tax for carbon-intensive goods imported into the territory, such as cement, steel, and fertilizer.[1] The decade that follows is marked by a series of high-profile

climate disasters: an unprecedented series of floods, heat waves, and hurricanes that make climate change unmistakable to a growing number of people. Climate alarm ratchets up to new heights around the world.[2]

In response, the EU expands its tax policy on carbon-intensive imports, inspired by an international agreement that established a carbon fee for global shipping in 2025.[3] Under the new rules, European airports charge incoming international flights a substantial fee based on the carbon intensity of their fuels. Jet fuel derived from corn ethanol is exempt from these taxes, as long as EU standards are met. The rules dictate that farms producing crops for biofuels must use no-till and cover cropping. Soon after, dozens of countries outside the EU respond with reciprocal fees.

These changes result in significant costs for American airline companies that fly internationally. They rush to scale up their “sustainable aviation fuel” (SAF) programs, many of which began at the beginning of the 2020s. The airlines lean most heavily on suppliers who source from biofuel producers in Minnesota and Illinois, where state tax credits became available for SAF in the early 2020s. Airlines and their suppliers offer purchase price bumps for growers in these states in exchange for the implementation of required tillage, cover crop, and nutrient management practices.

By the late 2020s, farm landscapes in the two states are smattered with rye, clover, and hairy vetch cover crops in late fall and winter. Waning demand for automobile biofuels, as electric cars make inroads in market share, makes these extra requirements a worthwhile trade for growers.

Midwestern states, and then Congress, expand support for sustainable aviation fuel

Sustainable aviation fuel becomes a boom industry for Minnesota and Illinois, and other Midwestern states quickly adopt similar incentives. Airlines offer generous advanced purchasing commitments for biofuel that meet sourcing requirements. Blending facilities that market to nearby airports pop up across the region, creating new manufacturing jobs in places like Moorhead[4], Sauget[5], Janesville, and Cedar Rapids.

By the mid-2030s, travelers departing from locations like Chicago, the Twin Cities, and Milwaukee are among few Americans not subject to “international carbon surcharges” that show up on booking websites when they purchase flights. Elected officials in the region regularly boast about their state’s role as a “global leader in sustainable aviation.”

Nonetheless, airlines are unable to source enough biofuel to avoid growing international carbon taxes. A coalition of large airlines, oil companies, and agribusiness interests lobby Congress to pass the “SAF Act,” providing an expansion of the Clean Fuel Production Tax Credit established in the 2020s, innovation grants, and public research and development funding.[6] A growing environmentalist faction in Congress reacts warily,[7] concerned that the biofuels' climate benefits are based on faulty accounting.[8] But they ultimately decide that industry lobbying is insurmountable, and strike a deal.

Federal SAF incentives become law, though the skeptics in Congress manage to add a set of riders designed to help the incentives improve water quality. For producers and buyers to be eligible for SAF tax credits, biofuel must be grown with a set of mandated best management practices: year-round cover, nutrient planning, reduced fertilizer application, and edge-of-field treatments become effectively mandatory. For other growers, most states offer strong incentives through their nutrient loss reduction strategies for voluntary adoption of the same practices.

The deal also has spillover benefits for state nutrient loss reduction efforts: Because the SAF Act is expected to bolster large-scale corn and soy agriculture, political pressure to meet goals to reduce the Gulf of America hypoxic zone grows. Substantial new funding also flows to Mississippi River Basin states and Tribal Nations for technical assistance and communications to help producers adopt promoted practices.

Conservation agriculture, fueled by aviation

In the late 2030s and early 2040s, new federal dollars fan out across the landscape. The proportion of SAF growers expands rapidly. By this point, automobile fuels use little corn ethanol, as cheaper electric cars have taken over the market.[9] So, SAF production provides a timely pivot for row crop farmers.

Installers of saturated buffers and bioreactors face frequent backlogs of work orders. Expanded cover cropping, the introduction of newly bred crop varieties,[10] and the milder winters of a warming climate mean much of the Midwest is green almost year-round. Winter drivers on regional highways, especially at lower latitudes, often remark on the stark visual change in the rural landscapes they drive past.

By the middle of the decade, around three-quarters of growers use some combination of cover crops, conservation tillage, nutrient management planning, and edge-of-field practices. And due to the combination of federal incentives, state incentives, and SAF price premiums, profits are up for many farmers compared to prior decades.

Advances in farm technology also provide a boost to SAF and conservation goals. Precision irrigation expands, especially in the western part of the Mississippi River Basin. New tools for precision nutrient application allow farmers to increase their return on investment in fertilizer and their fields' nutrient use efficiency. More producers use controlled drainage and flood retention infrastructure to recycle water and capture more of the nutrients it contains.

The U.S. Department of Agriculture and its Natural Resources Conservation Service hire a wave of new staff to track compliance with all the new requirements. There's a downside, though. Compliance is sometimes burdensome for farmers, especially those who are most protective of their privacy. They have to accommodate visits from inspectors, plus consent to having their land photographed via high-resolution satellite imagery to verify use of required practices. Regulators succeed in softening the burden somewhat by placing a renewed emphasis on efficiency and streamlined user experience.

Some critics also lament what they view as the narrowness of reformers' vision. Yield remains the overriding goal of American agriculture, with the bulk of each year's harvest not intended for human consumption. But on the other hand, as environmentally oriented management expands, "conservation agriculture" becomes almost an oxymoron; nearly all agriculture is conservation agriculture. For many, it becomes hard to imagine anything else, and earlier forms of production become relics of what seems like a distant past.

Footnotes: Real Ideas from Today

1 Carbon Border Adjustment Mechanism. European Commission. March 28, 2025.

2 Research indicates that whether or not people attribute extreme events to climate change has an important connection to what climate policies they support. See, for instance, Viktoria Cologna, Simona Meiler, Chahan M. Kropf, et al. (2025). "Extreme weather event attribution predicts climate policy support across the world." Nature Climate Change 15 (7): 725–35.

3 Jennifer McDermott and Sibi Arasu. (April 11, 2025). Major nations agree on first-ever global fee on greenhouse gases with plan that targets shipping. AP News.

4 Minnesota Sustainable Aviation Fuel Hub Overview. February 2025.

5 The Future of Fuel: How Illinois is Championing Sustainability in Aviation. Illinois Economic Development Corporation. January 6, 2025.

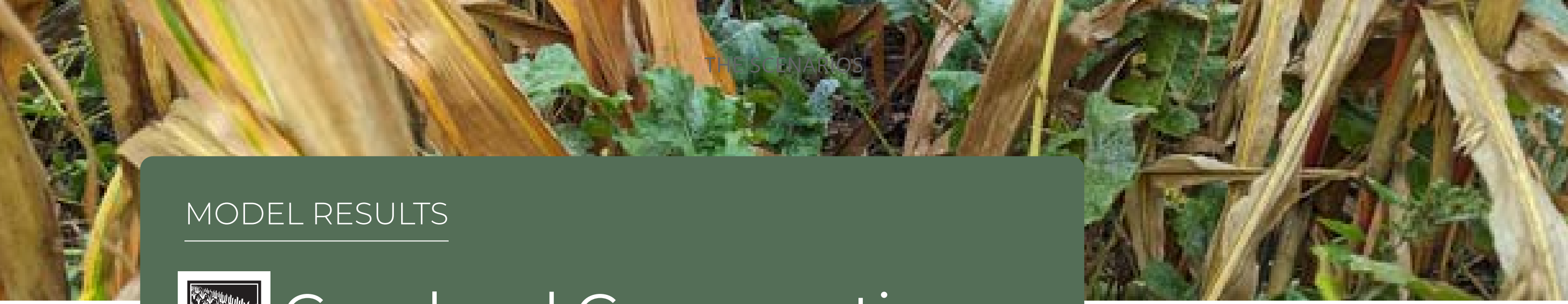
6 "Americans for Clean Aviation Fuels" is a coalition advocating for these policies. It includes Delta Airlines, ExxonMobil, the Iowa Soybean Association, and others.

7 See "Restoration Agriculture" for details on how this faction might grow.

8 For a present-day example of this concern, see Michael Grunwald. (May 27, 2025). The 'Green' Aviation Fuel That Would Increase Carbon Emissions. Yale E360.

9 See "Restoration Agriculture" for details on how corn ethanol use could decline.

10 Such breeding is underway at programs like the University of Minnesota's "Forever Green Initiative."



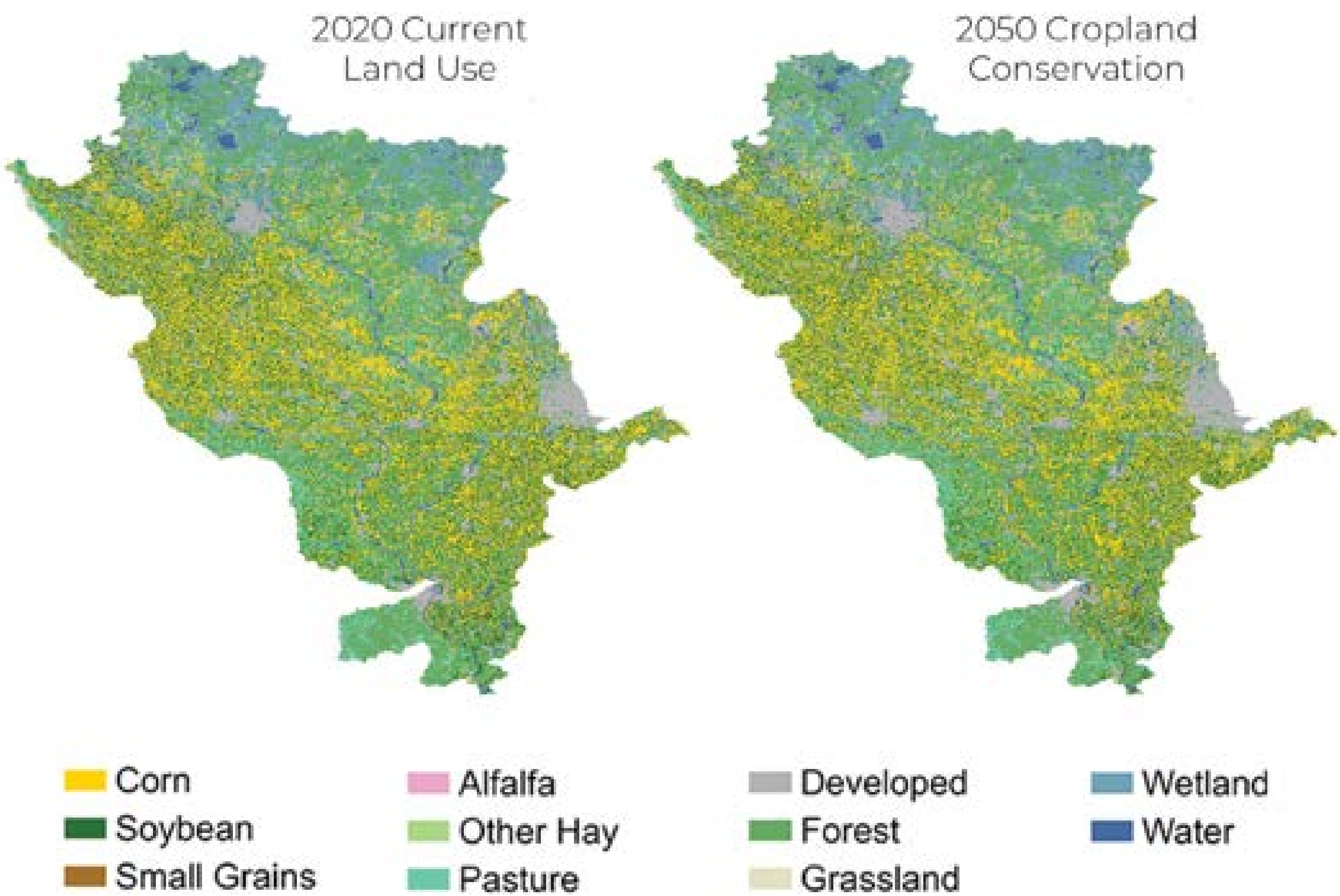
MODEL RESULTS

Cropland Conservation

Key Landscape-Related Changes by 2050

- Cover crops, no-till, and other conservation practices are each used on 75% of cropland. Edge-of-field treatments are used on 75% of suitable tile-drained cropland.
- Corn and soybeans have a land footprint nearly identical to 2025, and still supply meat, dairy, and crop exports.
- Fertilizer application rates have declined 25%.
- Due to the rise of electric cars, corn ethanol now primarily supplies aviation fuel.

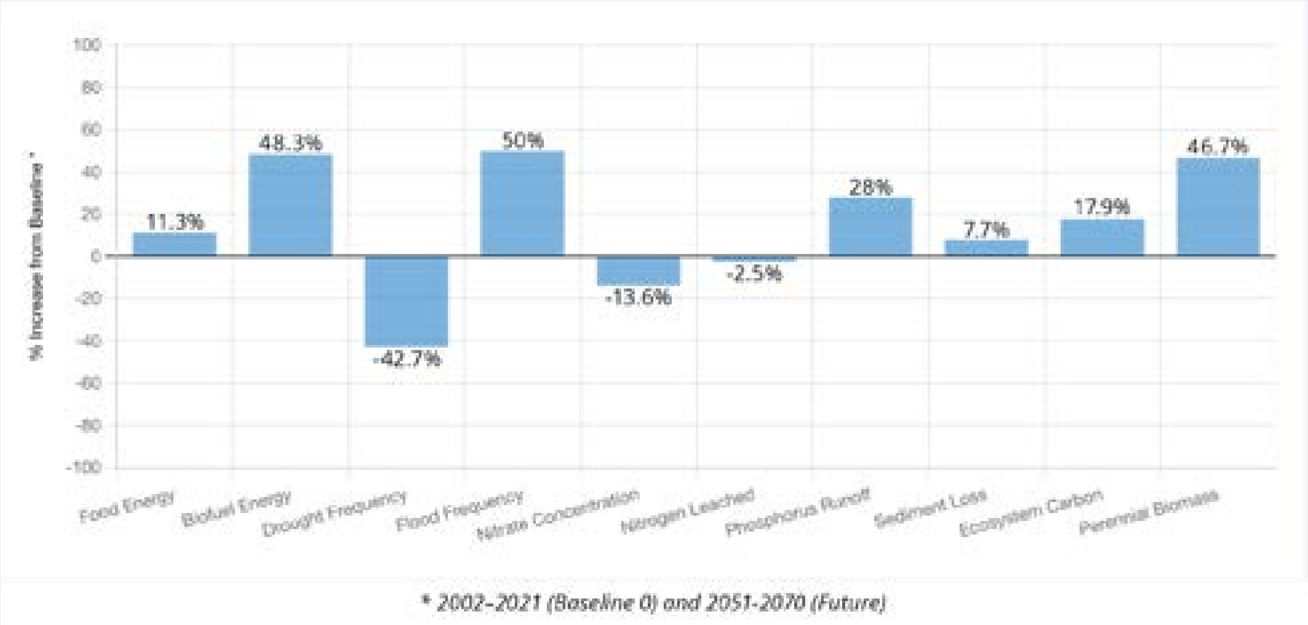
Land Use/Land Cover in This Scenario by 2050, Compared to Today



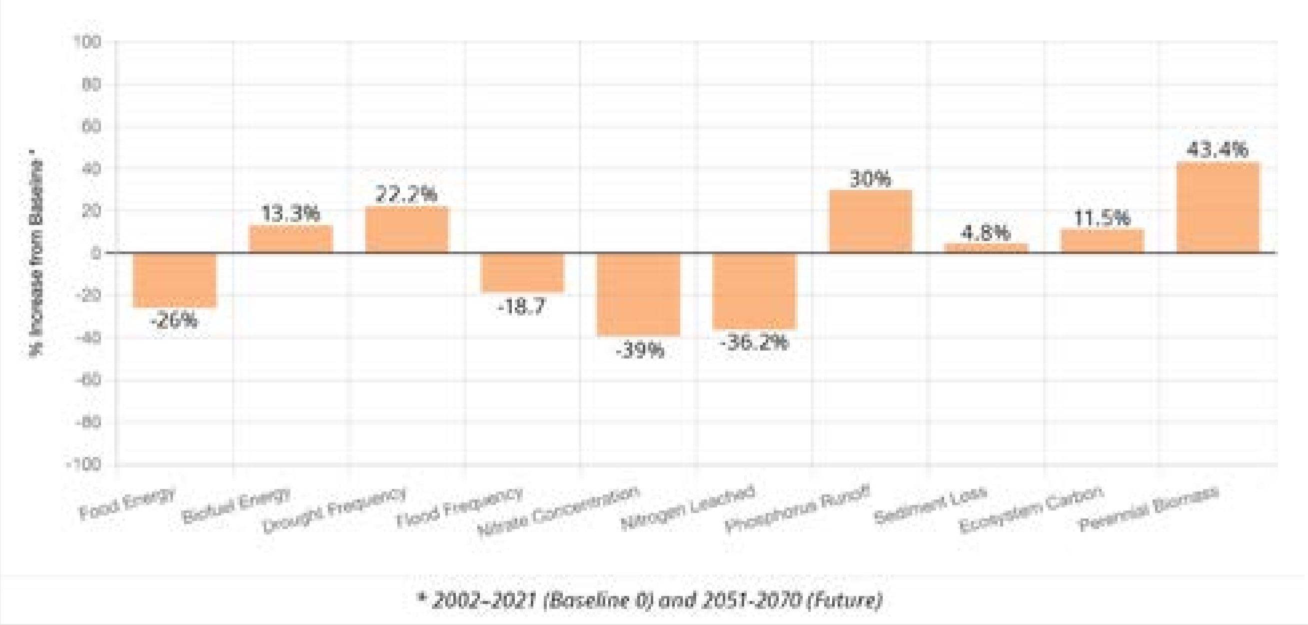
Outcomes for Food, Biofuel, Water, and Ecosystems

The model results represent outcomes for food production, biofuel production, water quality and quantity, and ecosystem health in this scenario by 2050. The outcomes will also be dependent on future climate conditions. The following climate projects, wet & warm and dry & hot, represent the two ends of the range of six total projections used in the models.

Wet & Warm Climate



Dry & Hot Climate



Key Takeaways from Cropland Conservation

The following takeaways describe how this scenario's model results compare to conditions today and to the model results of the other three scenarios. Unless specified, these takeaways hold for both the warm-and-wet and hot-and-dry climate projections.

2050 Versus Today

Biofuels boom, with ecosystem benefits

Under this scenario, biofuel production increases regardless of future climate conditions. The scenario assumes the biofuel industry primarily supplies aviation. At the same time, the region's croplands and ecosystems store more carbon and hold more perennial biomass than today.

A mixed bag for water quality

Nitrogen pollution improves, as high adoption of cover crops and saturated buffers reduces the amount of this nutrient reaching water bodies. On the other hand, phosphorus runoff worsens significantly. Even in dry climates, runoff from spring and fall precipitation drives phosphorus loss from this scenario's still-abundant annual cropland and the ample legacy phosphorus in soils.

For food and water supply, climate plays a decisive role

If the climate becomes warm and wet, food production ticks upward from present-day conditions, droughts become less common, and flooding becomes more frequent. Under hot-and-dry conditions, the inverse occurs—the region is marked by droughts and declining food crop yields.

Cropland Conservation Versus the Other Three Scenarios

Food: Second best for food production

Because a large fraction of the landscape continues to feed vehicles instead of people, Cropland Conservation is behind grazing-focused America's Pasture in food production. But the continued emphasis on row crop production generates enough food to reduce the impact of this tradeoff.

Biofuel: Best for biofuels

For people who want to maintain biofuels as a key industry for the Basin, Cropland Conservation is likely the scenario of choice. It's the only one that keeps a large share of land in biofuel-focused row crop production, and thus the only one without massive declines in biofuel output.

Water: Best for nitrogen, worst for phosphorus and sediment

As a result of widespread conservation agriculture practices focused on nitrogen, Cropland Conservation reduces nitrogen pollution significantly more than the other three scenarios. But the practices are less effective against phosphorus and sediment loss, and by midcentury there will be more legacy phosphorus in soils and a more extreme climate. For those reasons, Cropland Conservation results in setbacks larger than any other scenario for those indicators.

Ecosystems: Nature lags slightly

Ecosystem carbon increases at a magnitude roughly similar to the other scenarios, but perennial biomass is significantly lower—a consequence of keeping so much of the landscape in annual row crop production.

NARRATIVE

America’s Pasture

In 2050, more than half of all farmland is grazing land.

In the late 2020s and early 2030s, row crop farmers become fed up with perpetual debt and worried about the health of the landscapes they love. So they trade in the corn rows for cattle herds and sow perennial grasses in their fields. They rotationally graze the animals on their new pastures and sell milk and meat to eager local customers. It’s a handsomely growing market, arising out of a set of intersecting economic and social trends that began in the decade prior.

Americans turn toward local landscapes—and local food

In the 2020s, a new strain of American politics focuses on making gains in Americans’ health and fighting chronic illness. It combines wariness of modern medicine, disdain for large food and drug corporations, and an affinity for regenerative agriculture. More Americans avoid processed food. Messaging about regenerating soils and improving health outcomes resonates with some farmers.[1] In 2018, the market share held by large food

companies begins to edge downward. It dwindles through the 2020s as inflation hits food prices and Americans grow more wary of processed food.[2] It's also driven in part by rising use of weight-loss drugs, which cut Americans' appetites for junk food.

By the late 2020s, backlash grows to the wave of new technologies defining American life, including social media, smartphones, and artificial intelligence. Some states ban devices in schools.[3] Smartphone break-up handbooks become bestsellers, and many of them advocate that Americans replace the connectivity of apps and screens with connection to the ecoregions they call home:[4] a burgeoning sense of belonging to the Great Plains, the Driftless Area, the Northwoods, or the Mississippi River Basin.

As a result of all these trends, Midwesterners are increasingly willing to pay a premium for food that sustains the landscapes around them. Farmers' markets, farm-to-table restaurants, and community-supported agriculture programs become more common over the late 2020s and early 2030s. Intentional communities focused on healthy eating and small-scale farming pop up in American suburbs.[5] Due to growing customer demand, schools, hospitals, and other institutional buyers also ramp up their local food sourcing.

At the same time, electric vehicle adoption grows and biofuel feedstock prices falter. The growing demand for local beef and dairy drives some early adopters in the Corn Belt to transition from row crops to grazing, underpinned by the growing popularity of regenerative agriculture and new U.S. Department of Agriculture insurance schemes for perennial production.

Global economic convulsions reshape Midwest agriculture

Amid these trends, the "free trade" era of global commerce unravels. In the United States, Democratic administrations aim to boost domestic green industry with "Buy American" provisions, and Republicans raise tariffs with the goal of re-shoring lost manufacturing jobs. Headlines augur "the end of globalization"[6] and a "new era of US protectionism."[7] Other nations strike back with tariffs of their own. And following a pattern that first emerged during the COVID-19 pandemic,[8] countries periodically restrict food exports, especially in the wake of new climate-change-driven shocks. Cycles of retaliatory trade restrictions spiral across the decades that follow.

In the United States, imported fruits, vegetables, and meat rise in price.[9] By 2035, imports like bananas and avocados are premium goods that many shoppers forego. Other products formerly shipped in from abroad stop being available at all. Tariffs drive up the costs of imported fertilizer, and hurt American sellers, too. China, the largest purchaser of American soybeans, begins sourcing from Brazil and other major global producers instead.[10]

In speeches full of barbed rhetoric, politicians blame international rivals for the shortages. Invoking 20th-century “victory gardens,” they say that America now needs a wartime food system. Only this time the war will be fought through trade rather than on the battlefield. They exhort American farmers to serve their country by filling the gaps in food imports.

Many Midwestern growers respond to the call. Conversion to pasture offers them the chance to undercut the high prices of imported grass-fed beef. They also take advantage of a set of recent policy nudges that aim to support domestic markets. For instance, all beef products on shelves are now emblazoned with prominent labels indicating United States or foreign country of origin.

Some producers dot their new pastures with intercropped trees and gain a handsome profit selling fruit and nuts to customers priced out of imported alternatives. These new “silvopasture” systems also have the added benefit of reducing livestock stress from more frequent extreme heat. More traditionally minded growers plant apples and pears. Others, inspired by Native chefs working to revitalize Indigenous foodways,[11] supply locavore customers eager to try aronia, chokecherries, serviceberries, and other fruits endemic to the region.

Meanwhile, some growers graze cows or sheep around fields of solar panels, especially in the northern fringe of the Basin, where the new agrivoltaics replace tariffed Canadian electricity imports.

Statehouses support the grazing transition

As this transition gains momentum, environmental nonprofits and dairy business interests strike a grand bargain in Wisconsin.[12] Together, the groups persuade the state legislature to invest substantial funding in transitions to grazing. The state establishes a program providing technical support for transitions to grazing and structured buyouts of farmer debt as they shift to operations that are profitable but don’t generate enough revenue to keep up with existing debt service.

For farms that remain in row crops, the Wisconsin bill provides some incentives for cover crops and regenerative practices like no-till. Some climate groups balk at this compromise, as even grazed beef comes with substantial carbon emissions. But the incentives prove popular among growers, and the success of the bill inspires copycat efforts in other Mississippi River Basin states, where grazing incentive programs are folded into state nutrient loss reduction strategies.

Over time, pastureland acquires new meaning in farmers' collective imagination. Once seen as appropriate only on land too poor for row crops, perennial agriculture becomes a symbol of American strength. Grazing and agroforestry come to represent supremacy over international rivals—almost a matter of national security. "America's farms, America's food" bumper stickers become ubiquitous on roads across the Midwest, and many growers take pride in supplying customers in their own region.

In the 2040s, legislators in Washington, DC, aim to entrench these changes to protect against future dependence on imported food. Congress passes a Farm Bill with a 10-year plan to phase out row crop subsidies and overhaul the Environmental Quality Incentives Program to better serve graziers.[13] These changes spur grazing transitions among another wave of growers, and by the close of the decade, around half of former corn and soy land is in pasture.

Not everyone has bought into the new locally oriented mindset, though. Some longtime dairy farmers frown upon the lower per-acre beef and milk output of pastureland and continue to concentrate production in grain-fed operations. And some Americans also complain that the lower supply of grazed beef has led them to cut back on the cheeseburgers and barbecue they grew up eating. But by 2050, food markets have found a new, domestically oriented equilibrium, and memories of shortages fade.

Footnotes: Real Ideas from Today

1 Lisa Held. (August 19, 2025). Should Regenerative Farmers Pin Hopes on RFK Jr.'s MAHA? *Civil Eats*.

2 Kraft Heinz is not the only food giant in trouble. *The Economist*. July 17, 2025.

3 Andrew Demillo. (January 16, 2025). Banning cellphones in schools gains popularity in red and blue states. *AP News*.

4 The 2019 bestselling book *How to Do Nothing: Resisting the Attention Economy* by Jenny Odell advocates for cultivating bioregional identity as a way of breaking free from the technological "attention economy."

5 Caroline Kitchener and Maddie McGarvey. (August 8, 2025). This Ohio Farm Community Is a Mecca for the 'MAHA Mom.' *The New York Times*.

6 Andrew Ross Sorkin, Jason Karaian, Stephen Gandel, Lauren Hirsch, and Ephrat Livni. (March 24, 2022). Wall Street Warns About the End of Globalization. *The New York Times*.

7 James Politi, Aime Williams, and Sam Fleming. (February 1, 2025). 'A trade war on steroids': Donald Trump ushers in new age of US protectionism. *Financial Times*.

8 Theresa Falkendal, Christian Otto, Jacob Schewe, Jonas Jägermeyr, Megan Konar, Matti Kummu, Ben Watkins, and Michael J. Puma. (2021). "Grain export restrictions during COVID-19 risk food insecurity in many low- and middle-income countries." *Nature Food* 2 (1): 11–14. https://doi.org/10.1038/s43016-020-00211-7.

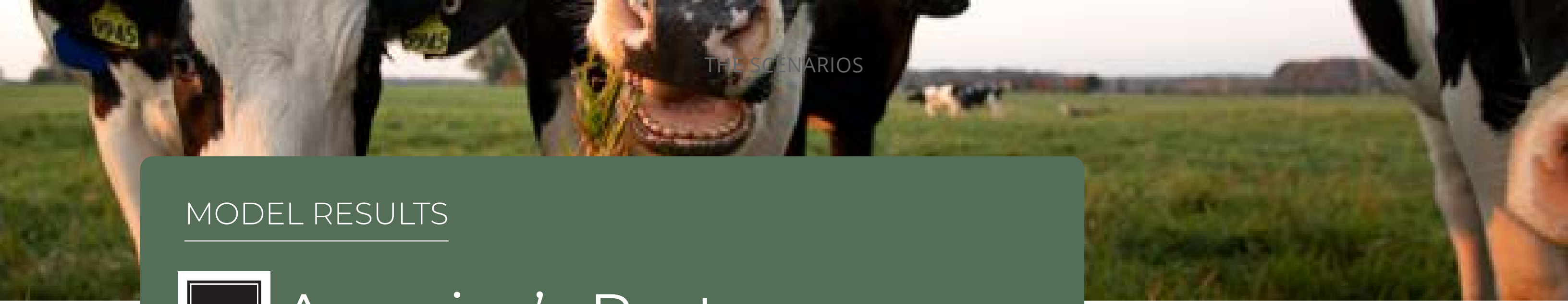
9 For most major food groups, the United States produces enough to theoretically feed the entire country's population, but not fruits and vegetables, according to the following: Jonas Stehl, Alexander Vonderschmidt, Sebastian Vollmer, Peter Alexander, and Lindsay M. Jaacks. (2025). "Gap between national food production and food-based dietary guidance highlights lack of national self-sufficiency." *Nature Food* 6 (6): 571–76. https://doi.org/10.1038/s43016-025-01173-4.

10 Bailey Schulz. (September 15, 2025). American farmers warn this year feels especially dire. What happens next? *USA Today.*

11 Kate Nelson. (May 20, 2025). Sean Sherman Expands His Vision for Decolonizing the US Food System. *Civil Eats*.

12 This deal builds on advocacy that began in the 2020s. It's also modeled after a similar "Green Tripartite Agreement" from Denmark in 2024. See the following: Danielle Kaeding. (April 14, 2025). "Bipartisan bill backs grazing practices that benefit Wisconsin water quality and livestock." *Wisconsin State Farmer*.

13 Erin Lower and Ana Fochesatto. (January 2023). Just Transitions to Managed Livestock Grazing: Needs and Opportunities for Change in Midwestern United States. *Grassland 2.0.*



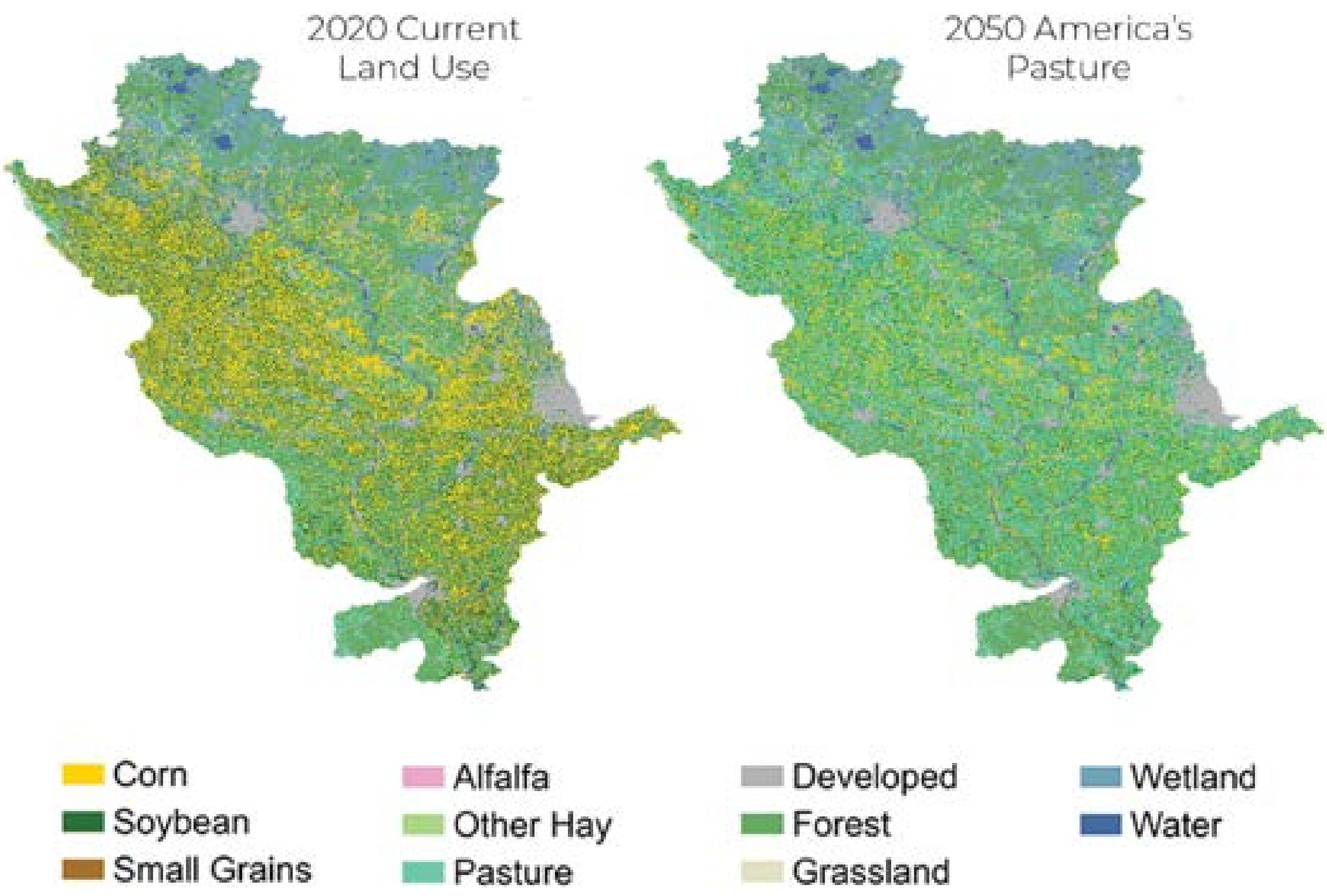
MODEL RESULTS

America's Pasture

Key Landscape-Related Changes by 2050

- Half of all cropland has been converted to perennial agroecosystems, including managed grazing and agroforestry.
- 50% of remaining annual croplands incorporate cover crops.
- Corn ethanol production has been virtually eliminated, due to the transition to electric vehicles.
- Americans consume slightly less total meat and dairy, but significantly more grass-fed animal products.

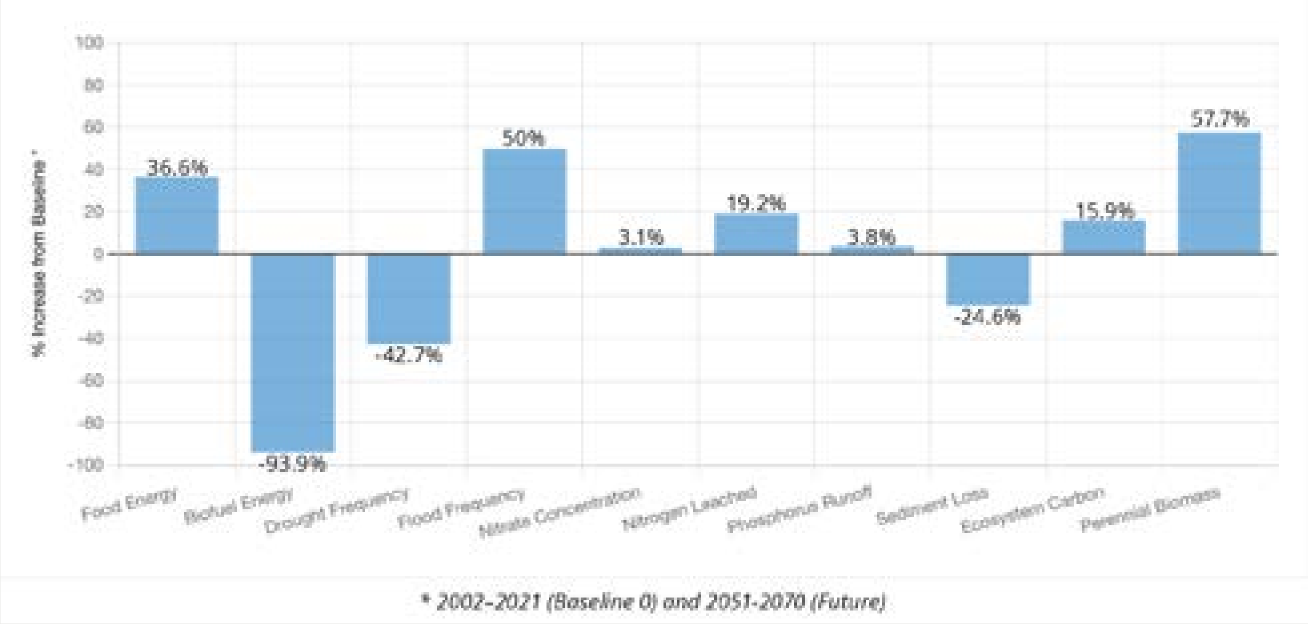
Land Use/Land Cover in This Scenario by 2050, Compared to Today



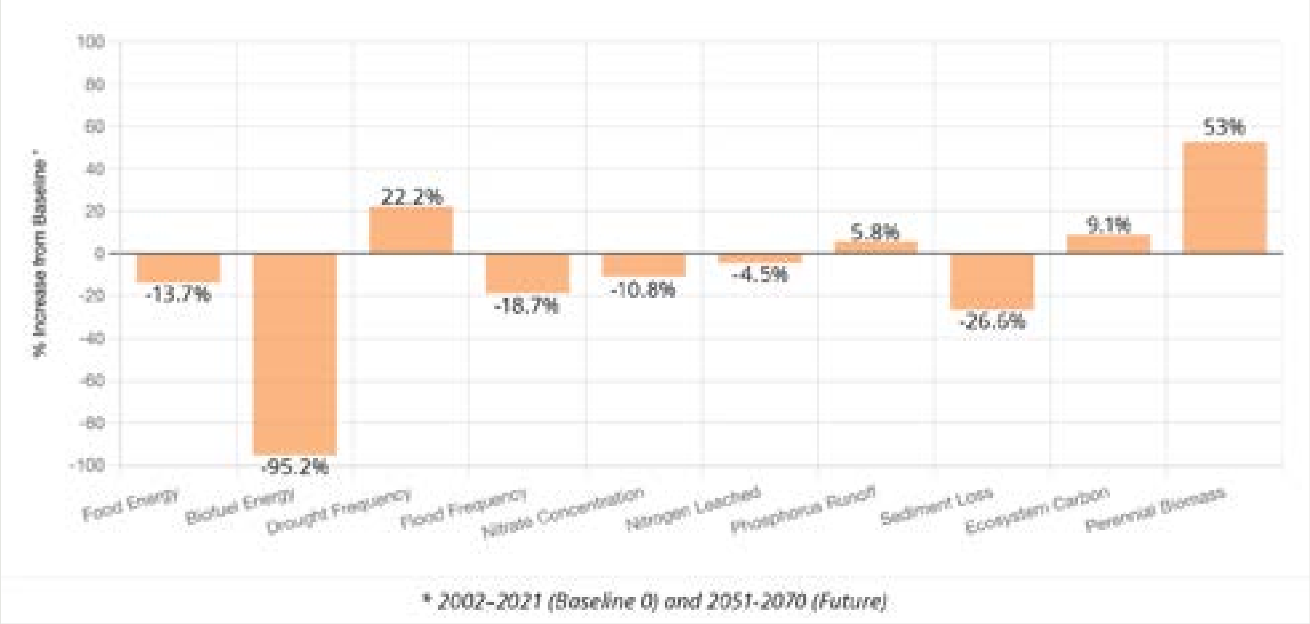
Outcomes for Food, Biofuel, Water, and Ecosystems

The model results represent outcomes for food production, biofuel production, water quality and quantity, and ecosystem health in this scenario by 2050. The outcomes will also be dependent on future climate conditions. The following climate projects, wet & warm and dry & hot, represent the two ends of the range of six total projections used in the models.

Wet & Warm Climate



Dry & Hot Climate



Key Takeaways from America's Pasture

The following takeaways describe how this scenario's model results compare to conditions today and to the model results of the other three scenarios. Unless specified, these takeaways hold for both the warm-and-wet and hot-and-dry climate projections.

2050 Versus Today

Depending on climate conditions, a possible boom in food supply

In wetter climates with moderate global warming, potential food supply increases substantially, with most of the landscape devoted to producing grain or grazed livestock. The increase in plant-based diets means humans directly consume more of that grain. In a hot and dry climate, a modest decline in food supply occurs, blunted somewhat by the growth in plant-based diets.

Biofuel production plummets

The transition to electric vehicles crushes biofuel demand, all but eliminating the industry and freeing up cropland area for alternative uses.

Big progress on stemming erosion, but nutrient pollution persists

The widespread conversion of farmland to pasture slows sediment loss but can't immediately address decades of nitrogen and phosphorus application. This legacy, plus stronger and more frequent storms, leads to a slight worsening of phosphorus runoff and a slight improvement at best in nitrogen leaching.

Gains in biodiversity and carbon storage

The conversion of landscape to pasture greatly increases perennial biomass, creating much more space for plant and animal life to thrive. These changes also lead to a more modest increase in carbon stored on the landscape.

America’s Pasture Versus the Other Three Scenarios

Food: Best for food production

This scenario is unique in that most of the landscape is devoted directly or indirectly to food production due to widespread dietary changes. Many former croplands are converted to pastures that raise grass-fed livestock, and remaining annual crops have been steered more directly to people’s plates.

Biofuel: Lowest biofuel production

America’s Pasture and Restoration Agriculture virtually eliminate biofuel production, meaning their output of bioenergy is significantly lower than Cropland Conservation and Hotspots for Transformation.

Water quality: Second best for phosphorus and sediment loss

America’s Pasture performs second best in phosphorus and sediment loss, behind Restoration Agriculture for both, with the smallest increase in phosphorus runoff and the second-biggest decrease in sediment loss. It does not differ much from the other scenarios in nitrate concentration and nitrogen leaching (apart from Cropland Conservation, which stands out for its high reductions in nitrogen loss).

Ecosystems: Neither best nor worst

Perennial biomass grows more than in the row-crop-dominated Cropland Conservation, but less than the other two scenarios, which focus more directly on ecosystem restoration. Total carbon on the landscape increases at a similar magnitude in all scenarios, although it remains slightly lower in this one than in the other three.

NARRATIVE

Restoration Agriculture

In 2050, farmers tend not just crops, but also restored forests, wetlands, and prairies.

In the 2030s, as increasingly frequent droughts and heat waves ravage fields, some producers begin rethinking what it means to be a farmer. They conclude that they must focus not just on feeding the world, but also on caring for the ecosystems on which the health of their lands depend. On their least productive lands, they begin planting local tree species, constructing wetlands, and restoring prairies. Because of market shifts that began decades prior, they're able to do so at little net cost to their bottom line.

An electric vehicle boom cuts into biofuel demand

The growth in biofuel production in the Midwest over the 2000s and 2010s turns into an economic liability for farmers. Through the 2020s, electric vehicle adoption continues along the exponential "S curve"[1] of growth that began at the beginning of the decade. Around 2030, electric vehicles establish a decisive economic advantage over their internal-combustion counterparts, fueled by high-efficiency silicon anode batteries and increasingly cheap daytime solar and wind power. Americans buying new cars can save thousands of dollars by going electric, and automakers begin to phase out gas-powered vehicles.

These changes leave producers of corn ethanol in the lurch. Purchasers cut back on orders, and growers scramble to plant alternative crops or find new markets for corn. Exports increase, as countries where climate change has harmed corn production look for alternate food sources. Because of these nations' lower purchasing power, revenues decline for growers. A small portion of producers take corn fields out of production entirely.

Extreme weather alarms consumers and forces more producers to pivot

The 2012 drought, 2020 West Coast wildfires, and 2024 Midwest heat waves prove a harbinger of things to come. Climate change intensifies over the course of the 2020s and 2030s, making those extreme events feel as though they are near-annual occurrences. Shocked American eaters grow more carbon conscious, especially Millennials, Gen Z, and younger generations born into the changing climate.

As extreme weather cuts into farm yields, food grows more expensive, and grain-fed animal products strain shoppers' budgets. Clever vegetarian chefs become social media stars. Their social media recipe videos often include a grocery store budget estimate and rough carbon footprint calculation. Dairy and beef consumption decline and plant-based diets boom.

In the wake of these changes, markets for biofuels and silage corn suffer further. Some producers begin to take land out of row crops, especially in Iowa, Illinois, and southern Minnesota. Persistent hot-and-dry conditions parch farmland that remains in production, raising the specter of a climate-change-fueled "second Dust Bowl."

In response, a "restoration agriculture" movement takes hold. It grows out of the push for regenerative agriculture in prior decades, led by multigenerational farmers worried about the fate of the landscapes for which their parents and grandparents had cared.

These producers discover that, due to the lower crop production from increasingly hostile weather, they are able to restore forests and wetlands in underperforming portions of their fields without sacrificing profits. Many manage to make restoration profitable by brokering deals with major corporations looking to purchase carbon credits to offset their emissions.[2]

Lawmakers overhaul the Farm Bill to fund ecosystem restoration

Together with voters alarmed by extreme weather, these farmers elect a wave of new Midwestern lawmakers with a mandate to protect rural lands. In the late 2030s, senators from Iowa persuade Congress to revamp federal farm subsidies. They pass a reimagined "Farm, Forest, and Landscape Bill" focused on nature-based solutions for climate change. It overhauls the Conservation Stewardship Program and Environmental Quality Incentives Program, vastly expanding the funding available and practices that qualify.[3]

The bill also provides a set of incentives for green infrastructure in urban areas. Developers start to incorporate more native ecosystems into construction, minimize impervious surfaces, and carve out green corridors that run through cities.

In line with national priorities, Mississippi River Basin states prioritize ecosystem restoration projects in their state nutrient loss reduction strategies. The states focus their energies for reducing nutrient pollution on nature-based solutions—such as wetland and floodplain restorations in agricultural areas and green infrastructure in urban areas. They create incentive programs for farmers to convert marginal and flood-prone cropland into natural ecosystems and for urban communities to install large and small-scale green infrastructure projects.

For large corporations, pressure to reach net-zero carbon emissions grows. They layer private carbon markets onto the new public programs, creating extra incentives for restoration in high-impact zones. Under the new programs, producers are able to enter an ecosystem service market that provides profitable long-term contracts to restore natural ecosystems on former farmland.

By the 2040s, thousands of young U.S. Department of Agriculture "Climate and Conservation Corps" employees fan out across the region each growing season in pickup trucks. Equipped with cutting-edge digital tools, they move from farm to farm conducting rapid biodiversity and carbon stock assessments. At each stop, they calculate preliminary results on a handheld tablet, often while their truck is still parked at the edge of each field. They then start the paperwork for a payment reimbursing producers for restoration costs, plus a stipend for each ton of carbon stored.

Fueled by these payments, restoration accelerates, and by 2050 half of former farmland is in the process of reconversion to its pre-agricultural state.[4] Grasslands and wetlands cover double the land area they did a few decades ago, and forest cover has increased by about a quarter. The change is especially pronounced in Iowa, Illinois, and southern Minnesota.

As agriculture across the world comes under increasing climate stress, some observers argue that, by moving land out of production, the United States is shirking its responsibility to help feed the world. As a result, some growers continue to focus primarily on row crop production, with an increased emphasis on food for humans to feed the plant-based diet market.

But many others now manage farmland woven into a mosaic of young forests, grasslands, and wetlands. A handful even abandon annual crops entirely and become full-time "forest farmers."

For most growers, federal incentives and payments from carbon markets become their cornerstone revenue streams. But they supplement them with a panoply of products sourced from the ecosystems they steward: sustainably harvested timber for green housing in growing cities; certified "restored prairie beef" that earns premiums in local markets; access permits for deer hunting in forests and sport fishing in streams; or foraged mushrooms sent off to cities like Minneapolis, Madison, and Des Moines, where chefs and customers are always on the hunt for the next trendy wild food.

Footnotes: Real Ideas from Today

1 The World Resources Institute has found that once electric vehicle sales reach 1% of passenger vehicle purchases in any country, growth accelerates. In Norway, electric vehicle sales went from 1% of the market in 2010 to 80% in 2022. Electric vehicle growth has started later in many other countries but is following a similar trajectory. See the following: Joel Jaeger. (December 5, 2025). These Countries Are Adopting Electric Vehicles the Fastest. *World Resources Institute.*

2 One such deal was struck in 2025 between Netflix and the American Forest Foundation, aiming to transition underused fields to forests. See the following: Mark Segal. (September 4, 2025). Netflix Signs 15-Year Carbon Credit Deal to Help Landowners Transition Fields into Forests. *ESG Today*.

3 The revamped programs are modeled off of Costa Rica's Payment for Environmental Services Program, which offered farmers 5- or 10-year contracts in which they receive cash payments in exchange for ecosystem restoration. These payments increased forest cover from around 25% of the country in the 1990s to almost 60% in 2020. See the following: Nell Lewis. (July 27, 2020). This country regrew its lost forest. Can the world learn from it? *CNN*.

4 These changes draw comparisons to New England, which was dominated by farms in the mid-1850s, but restored to more than 75% forest cover in many places by the early 21st century. See: David R. Foster, Brain Donahue, David Kittredge, Glenn Motzkin, Brian Hall, Billie Turner, and Elizabeth Chilton. (2008). New England's Forest Landscape: Ecological Legacies and Conservation Patterns Shaped by Agrarian History. In: Charles Redman and David R. Foster (Eds.), *Agrarian Landscapes in Transition*. (pp.44-88). Oxford University Press.

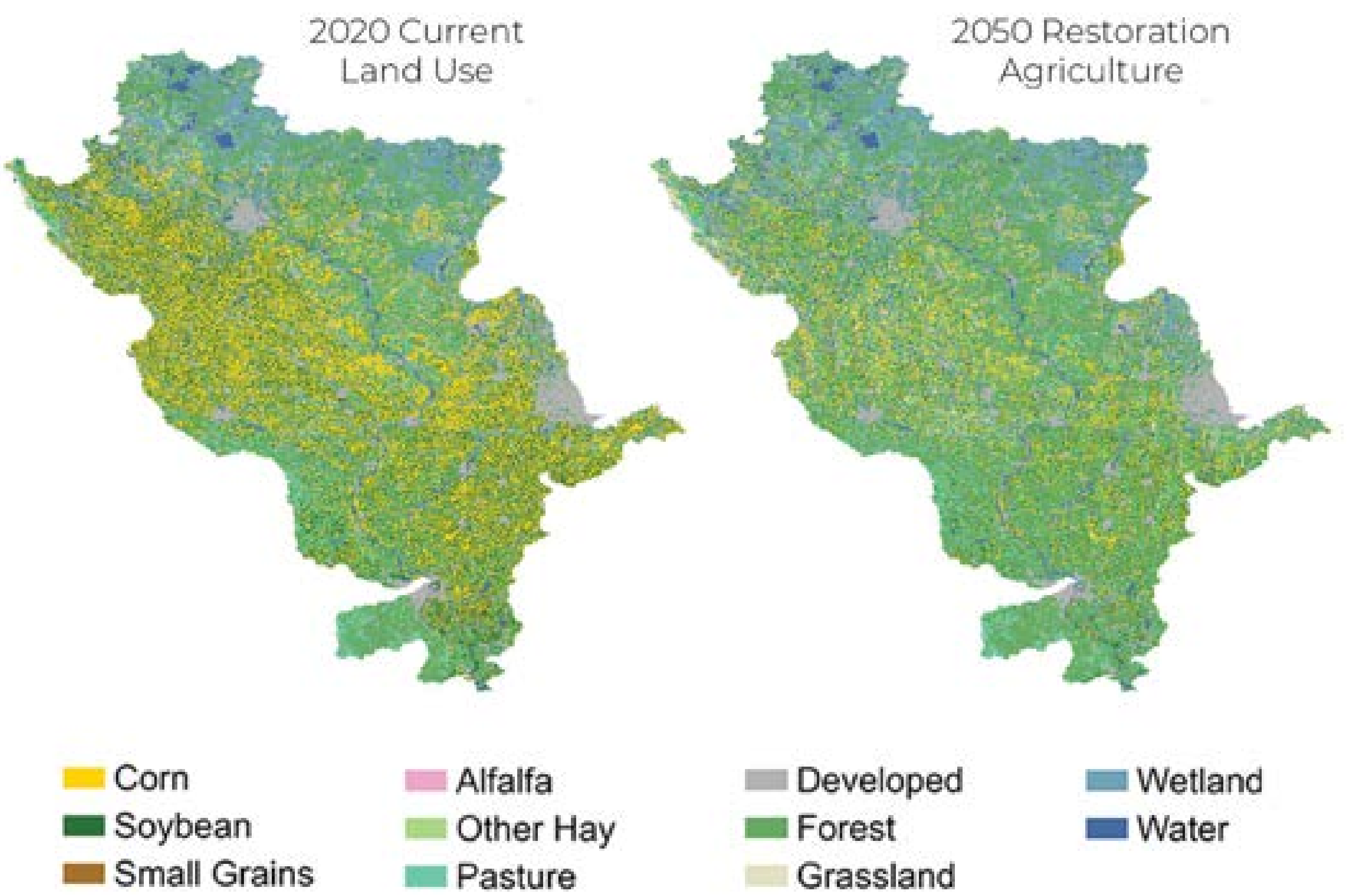
MODEL RESULTS

Restoration Agriculture

Key Landscape-Related Changes by 2050

- Half of all cropland has been converted to restored ecosystems, including wetlands, forests, and grasslands.
- “Payment for ecosystem services” programs allow farmers to make a living through a combination of crop production and ecosystem stewardship.
- Corn ethanol production has been virtually eliminated, due to the transition to electric vehicles.
- Plant-based diets boom; meat and dairy consumption declines significantly.

Land Use/Land Cover in This Scenario by 2050, Compared to Today



Outcomes for Food, Biofuel, Water, and Ecosystems

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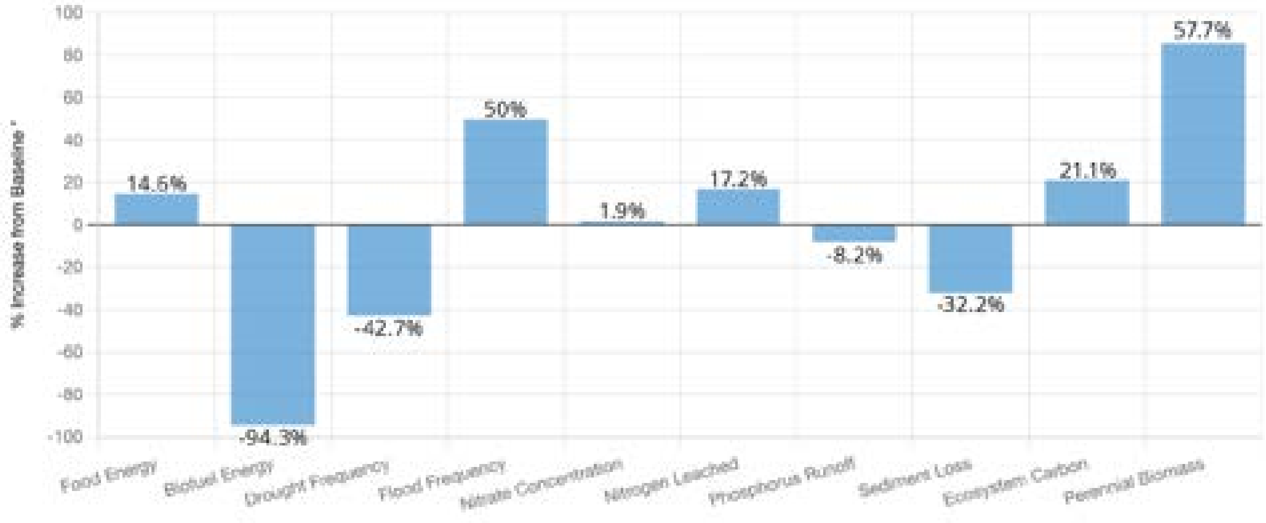
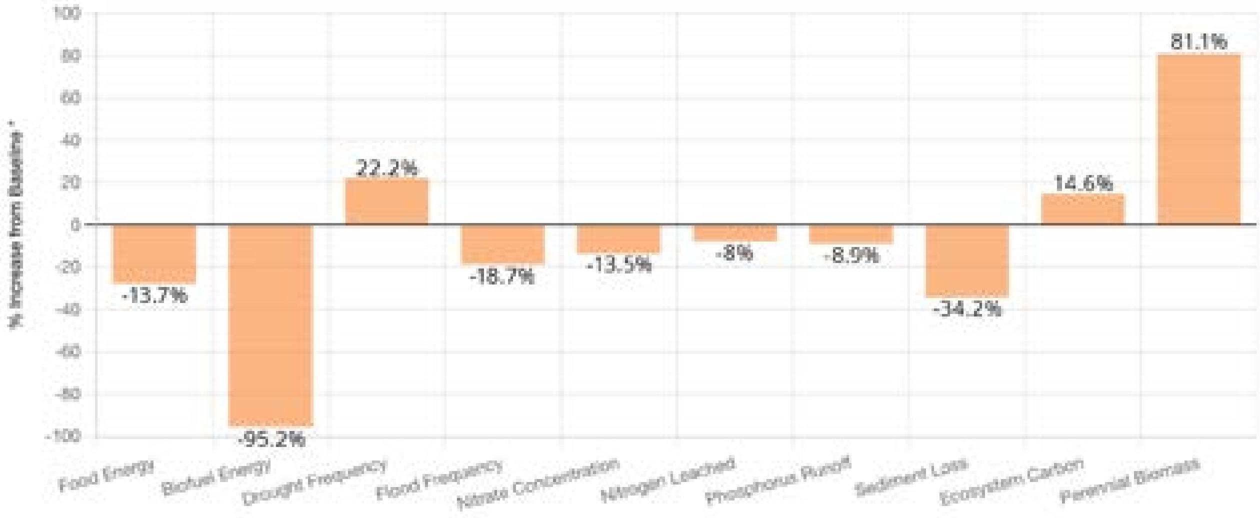
Wet & Warm Climate



** 2002–2021 (Baseline 0) and 2051-2070 (Future)*

Dry & Hot Climate



** 2002–2021 (Baseline 0) and 2051-2070 (Future)*

Key Takeaways from Restoration Agriculture

The following takeaways describe how this scenario's model results compare to conditions today and to the model results of the other three scenarios. Unless specified, these takeaways hold for both the warm-and-wet and hot-and-dry climate projections.

2050 Versus Today

Biofuel production plummets

The transition to electric vehicles crushes biofuel demand, all but eliminating the industry and freeing up cropland area for alternative uses.

For food supply, climate plays a decisive role

In a warm and wet climate, food production increases slightly compared to today. Cultivated area is reduced but due to the growth of plant-based diets, the share of harvests that go directly to humans increases. Under hot and dry conditions, the inverse occurs—the region is marked by droughts and declining food crop yields.

Big progress on stemming erosion, but nutrient pollution persists

The widespread restoration of former farmland slows sediment loss. Phosphorus runoff declines slightly, but legacy nutrients, plus stronger and more frequent storms, limit progress. Nitrate leaching declines slightly only under drier climate conditions, as restoration does not fully offset the continued nitrogen inputs to cropland that occur in the 2020s and 2030s.

Ecosystems thrive

Restoration leads to increased ecosystem carbon, and the region's perennial biomass nearly doubles, representing an explosion of new habitat for plant and animal life.

Restoration Agriculture Versus the Other Three Scenarios

Food: Neither best nor worst for food calories, but way less meat and dairy

The transition to plant-based diets in this scenario allows for its food supply to remain middle-of-the-pack on a smaller land base, but the composition of food supplied changes. Restoration Agriculture supplies fewer animal-based food calories than any other scenario.

Biofuel: Lowest biofuel production

Restoration Agriculture and America’s Pasture virtually eliminate biofuel production, meaning their output of bioenergy is significantly lower than Cropland Conservation and Hotspots for Transformation.

Water: Best for phosphorus and sediment loss

Restoration Agriculture is the only scenario to generate reductions in phosphorus runoff, with slight declines regardless of climate. It also reduces sediment loss more than any other scenario.

Ecosystems: Best for ecosystems

All scenarios show gains in ecosystem carbon and perennial biomass, but none as big as Restoration Agriculture. Perennial biomass especially shines, with gains significantly larger than Hotspots for Transformation, the second-largest gainer.

NARRATIVE

Hotspots for Transformation

In 2050, a mix of conservation agriculture practices, restored ecosystems, and perennial grazing land are strategically placed to maximize environmental benefit.

In the 2030s, new resources begin to flow into areas of the Upper Mississippi River Basin that have struggled most with water pollution. New federal, state, and private programs target hotspot water bodies, farm fields, or even subsections of a single field. They offer new resources that allow growers to pivot in a few different ways. Some pivot from row crop production to perennial grazing; others weave restored forests and wetlands into their fields; and others still incorporate conservation practices into their operations.[1]

The changes are hard-won, growing out of acute water quality challenges in prior decades.

Stronger storms cause water quality setbacks

Heavy rains become more common over the course of the 2020s due to the changing climate. Alternating drought and storms lead to increased nutrient runoff from farmland, and some producers increase fertilizer applications to keep up with the losses.[2]

Carried by runoff from farms and cities, nutrient pollution increases in rivers and lakes, reversing some of the water quality gains of prior years. Cities sometimes ban watering lawns to help water utilities keep up with the demand for nitrate-treated water.[3] In places with less treatment capacity, spikes of nitrates in drinking water make headlines. Some Americans become increasingly distrustful of the water coming out of their tap, especially in rural communities surrounded by intensive agriculture. At substantial cost, some families choose to purchase bottled water to drink rather than risk illness from episodes of pollution.

A wave of newly elected environmentally conscious lawmakers convince Congress to address water pollution by expanding support for state-level nutrient loss reduction strategies. A set of bills provides an infusion of federal funds to states in the Mississippi River Basin. The laws grant states discretion on how to use the funds, but programs must target “hotspots of concern” for water pollution identified through advanced satellite imaging and machine learning tools. These hotspots could be anywhere from small subwatersheds with high nutrient outflow, down to the level of a specific farm field or fraction of a field.

New resources transform some farms

Within eligible areas, the expanded funds include generous incentives for growers to either take marginal lands out of production, convert them to grazed pasture, or scale up conservation practices. The funding allows states and nonprofits to hire a cadre of technical assistance staff to support these transitions, increasing producers’ capacity to troubleshoot the nuances of conservation agriculture and grazing transitions.

New technologies from the 2020s also bolster targeted land conversion. By the 2030s, most farmers use precision agriculture tools, drone imaging, and AI-powered calculations to much more accurately measure which portions of their fields turn a profit or loss. Calculation tools seamlessly incorporate government incentives and generate reliable recommendations of when marginal land conversion is most profitable.

The new tools are paired with smart technology that allows farm equipment to work around even very small patches of restored land. The software churns out statistical modeling that indicates where micro-restoration or conservation practice use should take place, and once the practices are implemented, scanning software generates a report to government regulators to initiate incentive payments.

Rural landscapes diversify

Over the course of the 2030s and 2040s, rural landscapes become an increasingly diverse patchwork of land uses. Corn ethanol production declines due to the growth of electric vehicles, though a portion of producers are able to pivot to supply airlines' aviation fuel needs, taking advantage of state tax credits.[4]

Some growers lean on the expanded incentives to transition most of their lands to grazing, supplying urban consumers who are increasingly interested in local food and increasingly struggle to afford imported food products due to global trade barriers.[5] Others draw on a combination of nutrient loss reduction incentives, plus new public–private "payment for ecosystem service" partnership programs, and restore portions of their field to natural forest or wetland.[6]

Because of the focus on hotspots, these changes proceed unevenly across the landscape, and converted lands are concentrated in the areas that received the most external support. Proponents herald the efficiency of this approach, with government dollars going to areas where bang for buck is the greatest. The generosity of these incentives leads to debate over where the boundaries of priority areas should be drawn, and some farmers joke that they'd better increase their nutrient runoff so they can become eligible for federal incentives.

Nonetheless, by 2050, cover crops and edge-of-field treatments are more widespread, and producers have converted around 15 percent of cropland to perennial agriculture or restored ecosystems.

Footnotes: Real Ideas from Today

1 For more details on how these transitions could happen, see the other three scenarios of this project.

2 Matthew Houser and Diana Stuart. (2020). "An accelerating treadmill and an overlooked contradiction in industrial agriculture: Climate change and nitrogen fertilizer." *Journal of Agrarian Change* 20 (2): 215–37. https://doi.org/10.1111/joac.12341.

3 Julia Jacobo. (June 16, 2025). First-ever ban on watering lawns in central Iowa due to nitrate levels in rivers. *ABC News*.

4 See "Cropland Conservation" for more details on how this change could occur.

5 See "America's Pasture" for more details on how this change could occur.

6 See "Restoration Agriculture" for more details on how this change could occur.

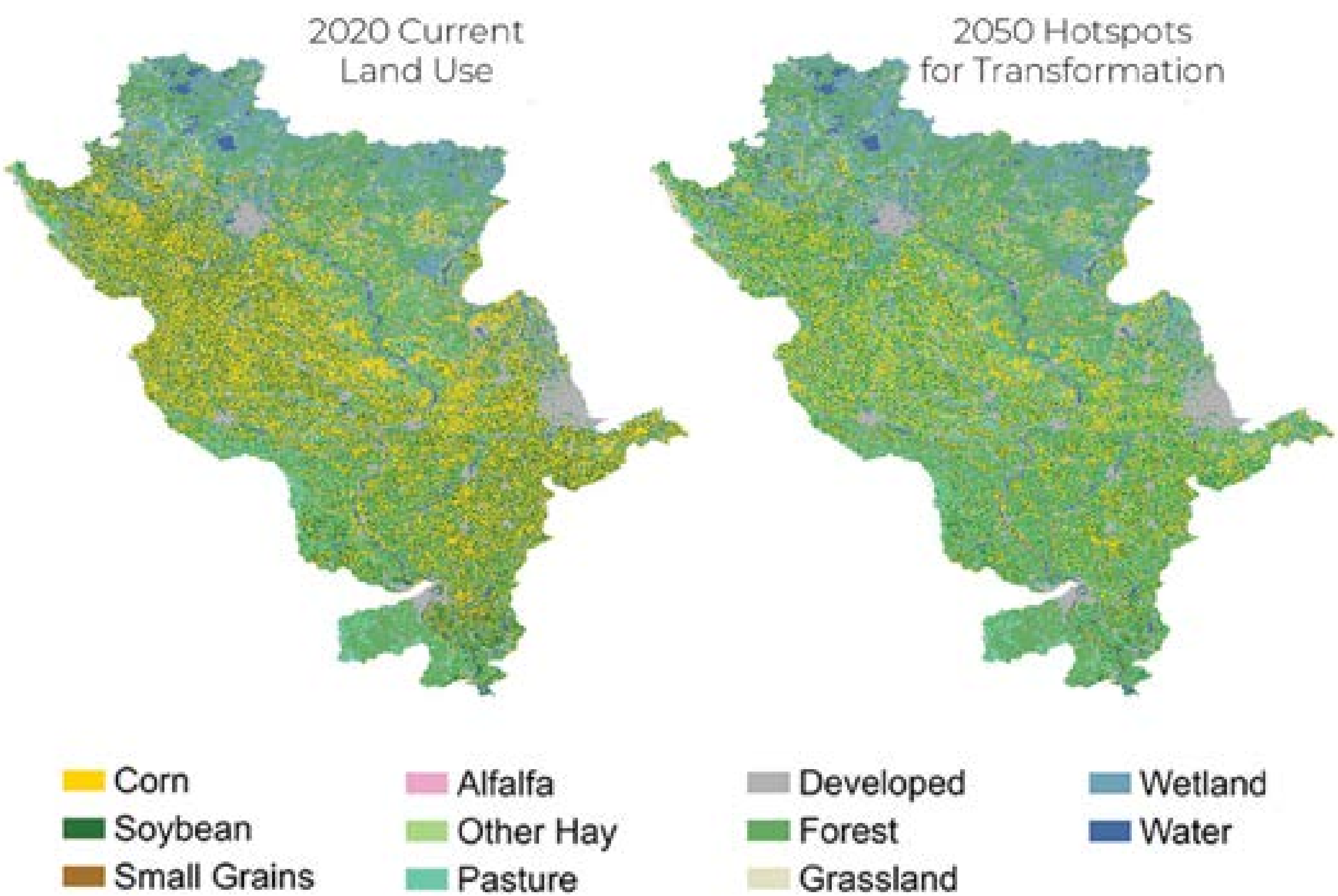
MODEL RESULTS

Hotspots for Transformation

Key Landscape-Related Changes by 2050

- Policies target nutrient runoff hotspots for conversion to conservation agriculture, restored ecosystems, or perennial grazing land.
- 15% of total cropland has been converted to a combination of restored ecosystems and perennial agriculture.
- 40% of agricultural lands incorporate cover crops, but their costs limit wider coverage.
- Corn ethanol production has decreased due to vehicle electrification but still exists to produce jet fuel and other bio-based consumer products.

Land Use/Land Cover in This Scenario by 2050, Compared to Today



Outcomes for Food, Biofuel, Water, and Ecosystems

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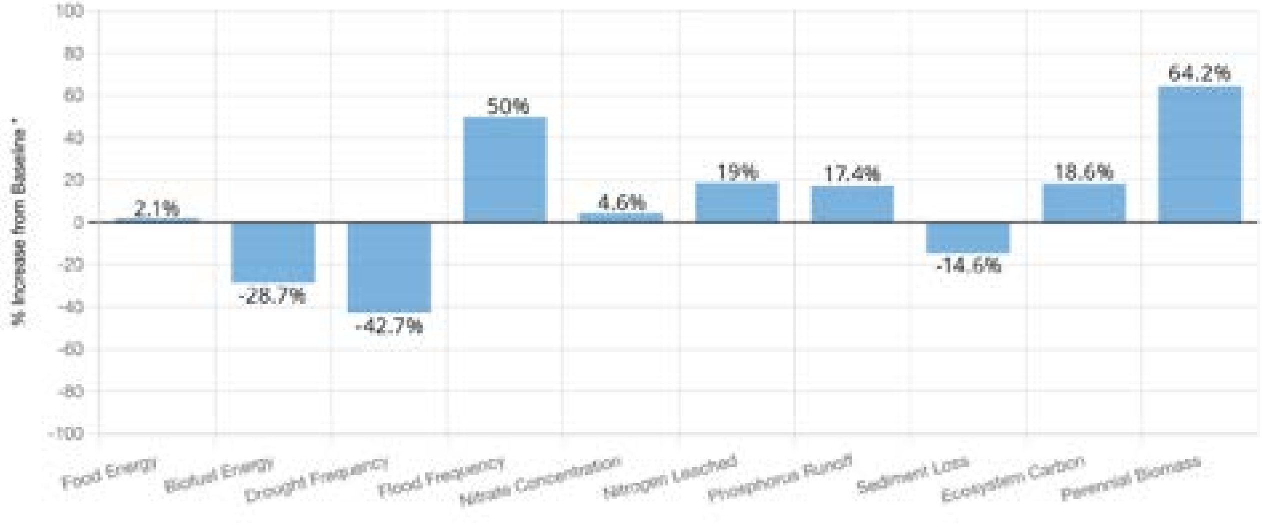
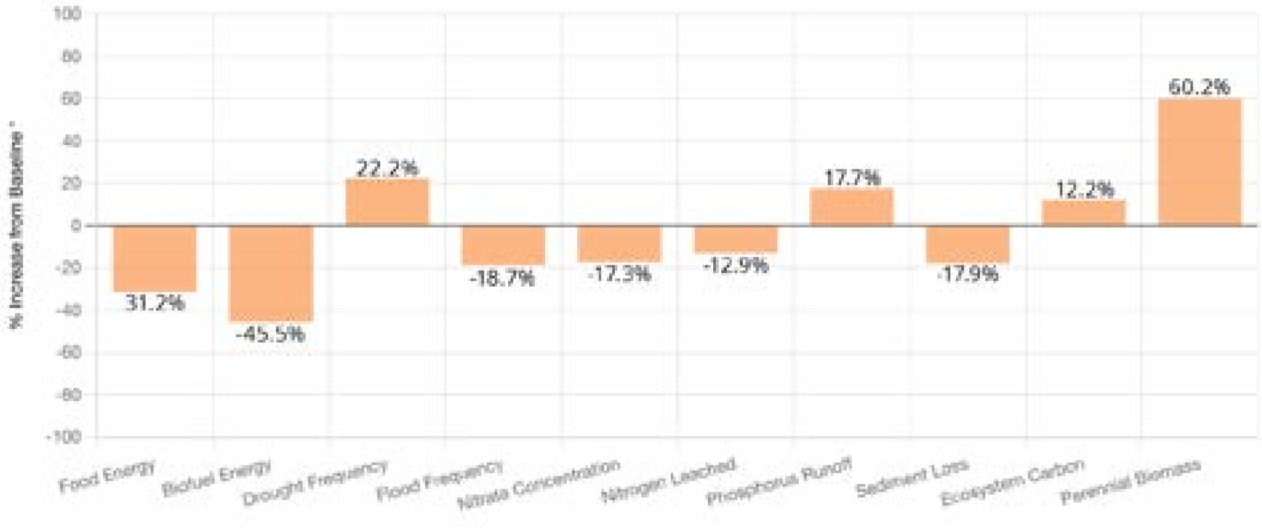
Wet & Warm Climate



* 2002–2021 (Baseline 0) and 2051-2070 (Future)

Dry & Hot Climate



* 2002–2021 (Baseline 0) and 2051-2070 (Future)

Key Takeaways from Hotspots for Transformation

The following takeaways describe how this scenario's model results compare to conditions today and to the model results of the other three scenarios. Unless specified, these takeaways hold for both the warm-and-wet and hot-and-dry climate projections.

2050 Versus Today

Depending on climate, food production remains either unchanged or declines

In a warm and wet climate, the region produces about the same amount of food energy as in 2020 (but less food per person, due to population growth). In a hot and dry climate, food yield declines substantially.

The biofuel industry shrinks but doesn't disappear

Biofuel production is way below today's levels—about a 25 percent to 50 percent decline, depending on climate conditions. But the region still retains significant production to supply producers of plant-based aviation fuel.

Less sediment loss but more phosphorus runoff

Some adoption of cover crops and transition away from annual crops reduces erosion in the Basin. Continued annual cropping, legacy nutrients, and stronger storms, though, mean that phosphorus runoff worsens somewhat regardless of climate conditions.

Climate is decisive for nitrogen

In a hot and dry climate, reduced growing season rain leads to modest improvements in nitrogen leaching. In a warm and wet climate, nitrogen leaching worsens somewhat.

Gains in biodiversity and carbon storage

The conversion of landscape to pasture and restored ecosystems increases perennial biomass on the landscape, creating more space for plant and animal life to thrive. These changes also lead to a more modest increase in carbon stored on the landscape.

Hotspots for Transformation Versus the Other Three Scenarios

In general, middle-of-the-road outcomes

Because this scenario is a composite of the other three, its results, in most cases, amount to “averaging” the outcomes of the others, blunting the biggest positive and negative changes.

Food: Worst for food production

Like America’s Pasture and Restoration Agriculture, this scenario takes significant land out of annual agriculture. But unlike in those scenarios, diets don’t change and biofuel production continues. The result is less food available for humans than any other scenario.

Biofuel: Second highest biofuel production

Like Cropland Conservation, biofuel production continues; but unlike Cropland Conservation, biofuel production does not grow.

Water: Neither best nor worst

The growth of conservation agriculture means, in a hot and dry climate, Hotspots lags behind only Cropland Conservation in nitrogen runoff reductions. Otherwise, the scenario has middle-of-the-road outcomes for nitrogen, phosphorus, and sediment loss.

Ecosystems: Second best for perennial biomass and ecosystem carbon

The combination of grazing land and restored ecosystems puts Hotspots behind Restoration Agriculture as second best for both perennial biomass and ecosystem carbon.

Comparing Model Results Across the Scenarios

Projected Outcomes for Food, Energy, Water, and Ecosystems in 2050

Produced with mathematical, process-based agroecosystem models, the model results project what each scenario might mean for food, bioenergy, water, and ecosystems by 2050. The results show tradeoffs and opportunities between these basic needs.

Compare outcomes across the scenarios and between the two different climate projections with the figures below. The modeled baseline for 2002–2021 represents historical land use/land cover, and the modeled future conditions represent the time period 2051–2070.

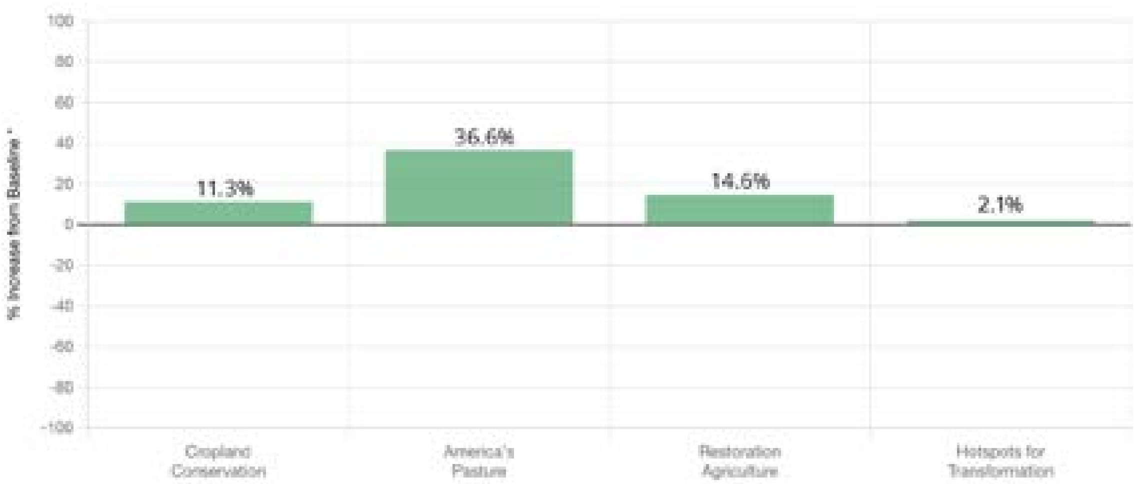
Food Energy

Food calories from crops and animal products

Total annual production of food calories across the Basin, including food for direct human consumption and the indirect contribution to human calories from animal feed. Considers dietary changes that occur in each scenario and indicates the Basin's potential contribution to regional and global food supply.

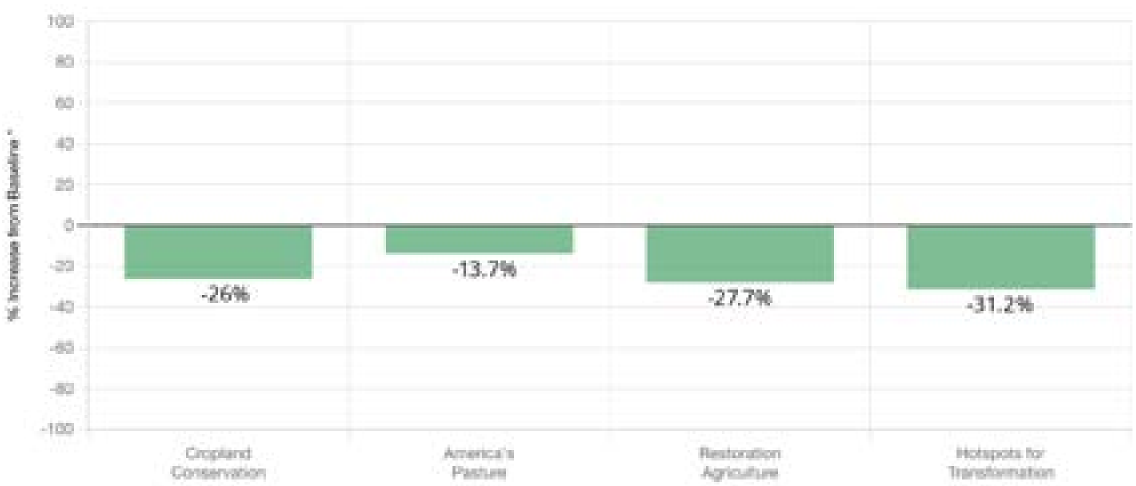
Food Calories

Wet & Warm Climate



* 2002–2021 (Baseline 0) and 2051-2070 (Future)

Dry & Hot Climate



* 2002–2021 (Baseline 0) and 2051-2070 (Future)

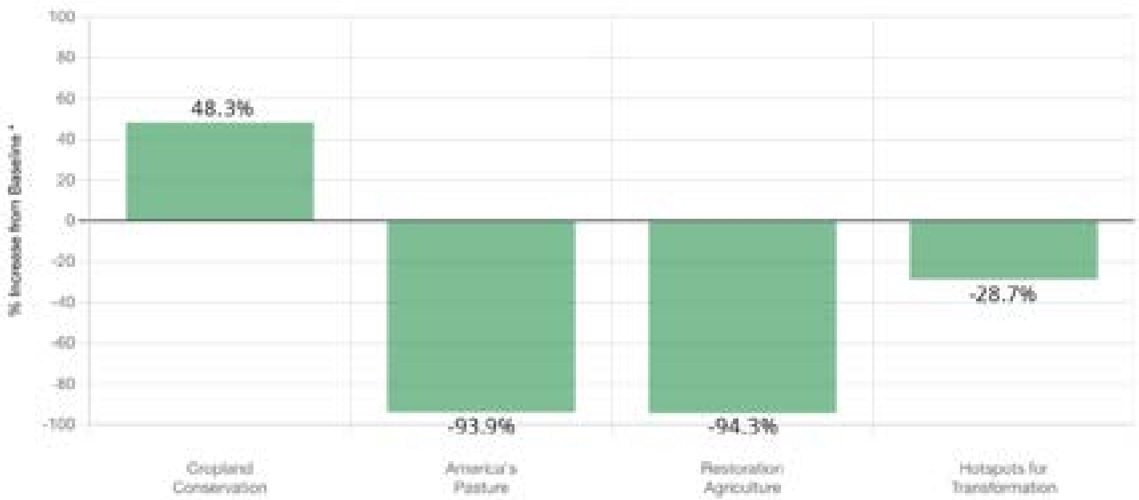
Biofuel Energy

Production of biofuel energy

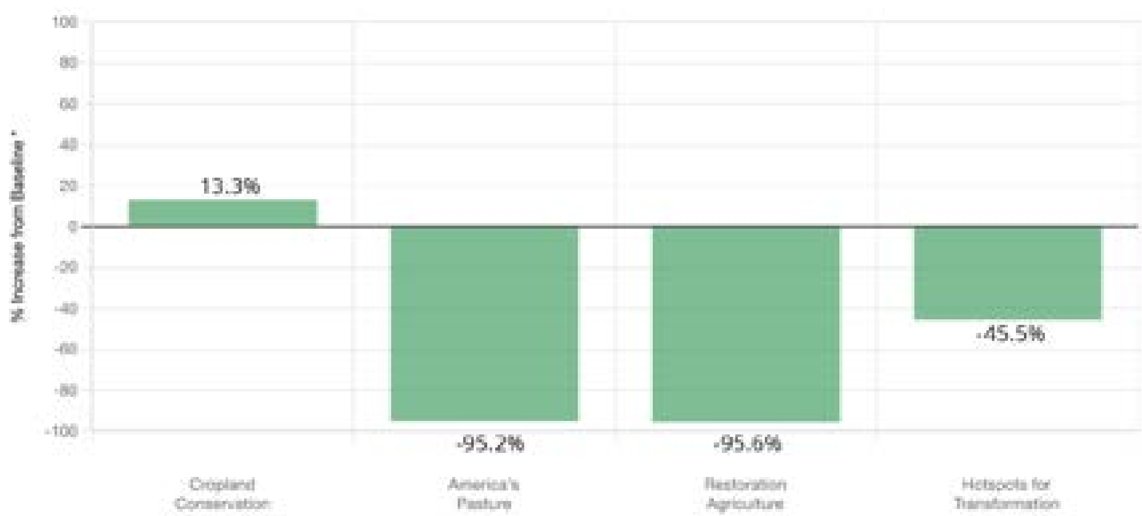
Total annual production of biofuel energy, in petajoules, from corn and soybean in the Basin, after accounting for energy losses.

Petajoules of biofuel energy

Wet & Warm Climate



Dry & Hot Climate



** 2002-2021 (Baseline 0) and 2051-2070 (Future)*

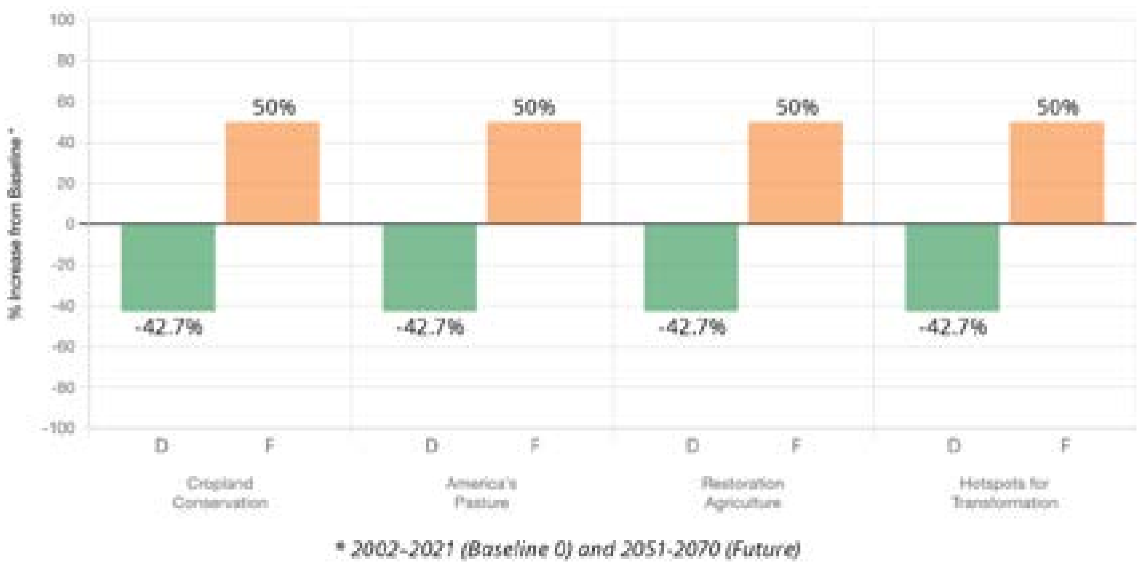
Water Quantity

Average frequency of drought or flooding

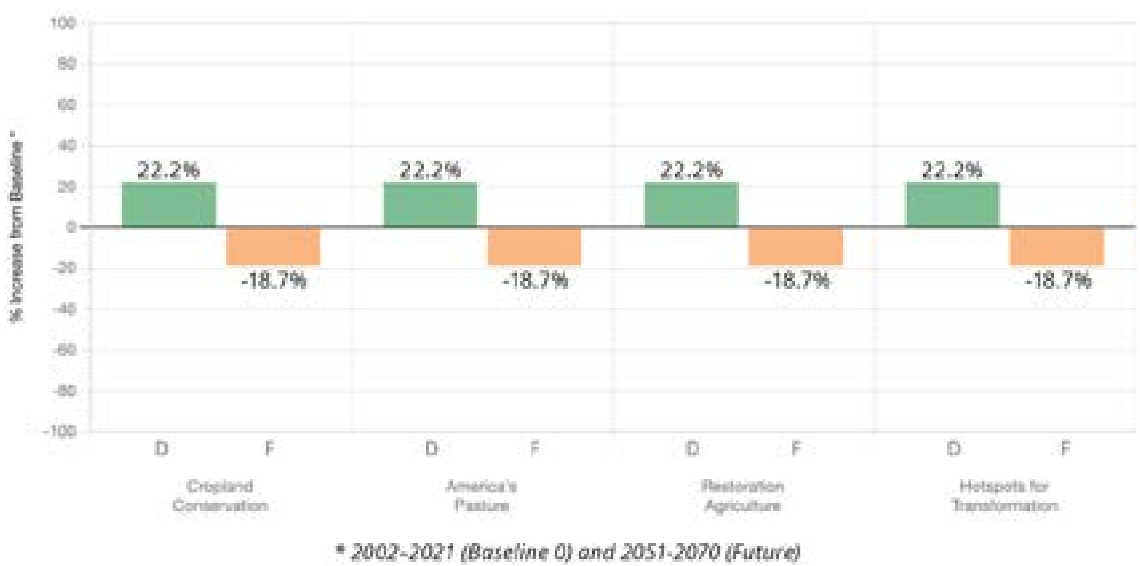
Uses outflow metrics from Grafton, Illinois, to indicate possible flood or drought risk. Flood frequency is the change in total time the Mississippi River is at “moderate” or worse flood stage. Drought risk is the change in total time the Mississippi River is below the 10th percentile of historical flow. *Note: Grafton represents the best available data but may not be representative of flood or drought frequency across the Basin.*

Drought Frequency   Flood Frequency

Wet & Warm Climate



Dry & Hot Climate



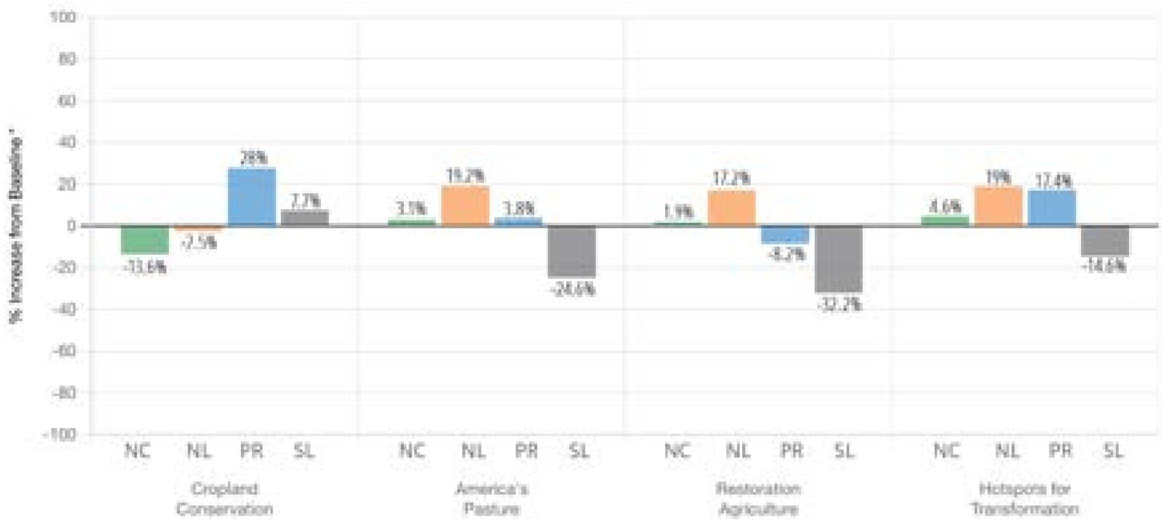
Water Quality

Nutrient and sediment loss across the Basin

Represented by four variables: The average concentration of nitrate in water that leaches out of plant root zones; the total amount of nitrate that leaches annually from plant root zones; the total annual phosphorus loss from surface runoff; and the total annual sediment loss from land surface runoff.

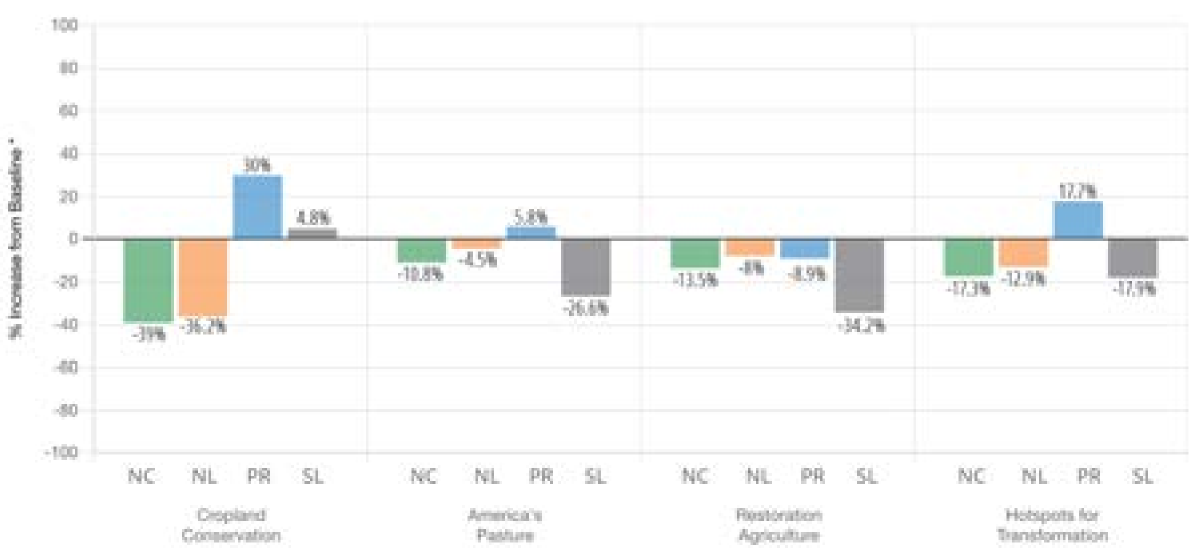
Nitrate Concentration | Nitrogen Leached | Phosphorus Runoff | Sediment Loss

Wet & Warm Climate



** 2002-2021 (Baseline 0) and 2051-2070 (Future)*

Dry & Hot Climate



** 2002-2021 (Baseline 0) and 2051-2070 (Future)*

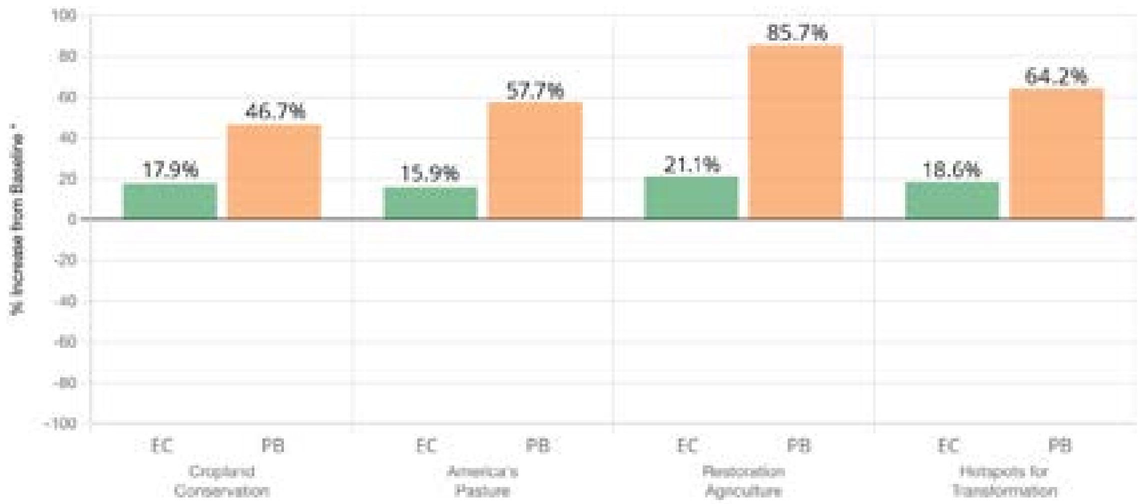
Ecosystem Quality

Total perennial biomass and carbon storage

Perennial biomass is the total weight of all perennial plants in the region—including forests, grasslands, pasture, and wetlands—as a proxy for biodiversity. Carbon storage is the amount of carbon in aboveground plants, soils, and belowground biomass, an indicator of less carbon contributing to global warming when carbon storage increases.

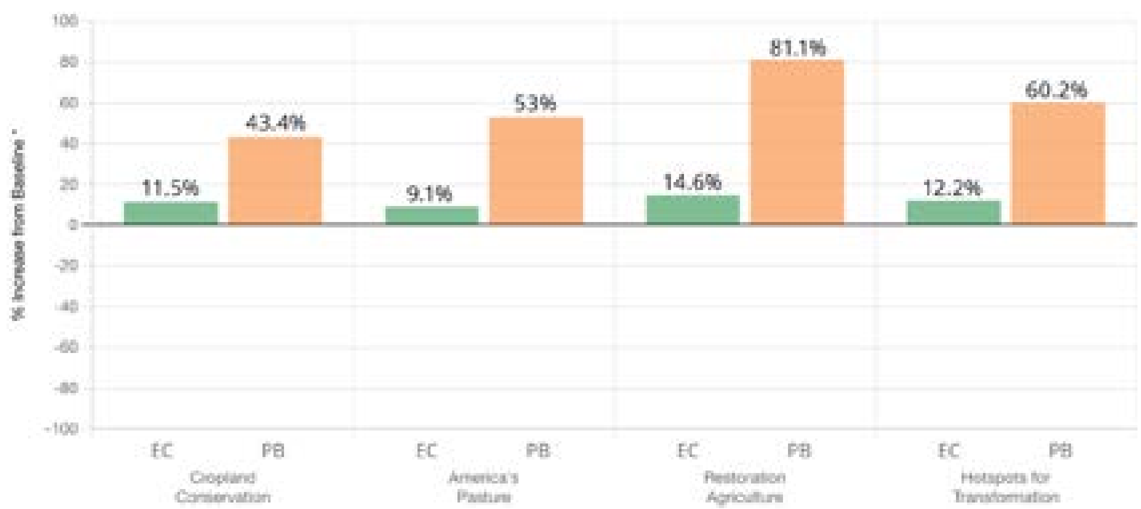
Ecosystem Carbon   Perennial Biomass

Wet & Warm Climate



* 2002-2021 (Baseline 0) and 2051-2070 (Future)

Dry & Hot Climate



* 2002-2021 (Baseline 0) and 2051-2070 (Future)

Implications of the Scenarios for Policy and Management

While the FEWscapes scenarios are hypothetical visions for ways land use and climate change could unfold over the next few decades, they provide real implications for policy and management decisions today. The following are some of the major implications identified by the research team.

Change Can Happen Fast, and Transformative Change is Necessary

Two overarching implications of the FEWscapes scenarios are that (1) while some changes can happen fast, ecosystem responses to those changes can happen much more slowly; and (2) achieving goals for food, energy, water, and ecosystems is going to require transformative land-use change.

The FEWscapes scenarios demonstrate that planning for a future based on today's status quo will be inadequate. Accounting for changes—whether gradual or sudden—in policies and management strategies is necessary to navigate the path toward a desirable future.

Moreover, despite the significant landscape and societal changes that occur in the scenarios, none of the scenarios hit the targets for food production, low-carbon energy, water quality, and ecosystem health that guided our scenario development process. However, a few came close for certain targets.

- America's Pasture achieves a 36.6% increase in food production in a wetter climate with less warming, which is just shy of the 40% increase target established by the U.S. Department of Agriculture.
- Cropland Conservation in a drier and hotter climate gets the closest to the 45% nutrient loss reduction target set by the U.S. Environmental Protection Agency for the Mississippi River Basin. It achieves a 39% reduction in nitrate concentration and 36.2% reduction in nitrate leaching.
- All scenarios, and especially Restoration Agriculture, have significant increases in perennial biomass, a proxy for increased habitat, which indicates multiple approaches can make progress toward the target to conserve 30% of land for biodiversity.

Achieving the goals will also require averting the worst-case climate projections through climate mitigation strategies. Our model results illustrate that it will be difficult to adapt to climate change and achieve goals for food, energy, water, and ecosystems through land-use change alone.

Overall, our results indicate that, if decision-makers and practitioners want to achieve the targets by 2050, they may need to consider even more profound transformations than the ambitious scenarios we developed.

Water Quality Improvements Will Take a Long Time

Legacy nutrients are nutrients that have built up over decades and centuries in our soils, and they are slow to disappear. Our model results confirm the persistence of phosphorus and nitrogen in the system, even despite transformational changes.

In fact, only one scenario, Restoration Agriculture, reduces phosphorus runoff at all.

The story is similar for nitrogen. Only one scenario, Cropland Conservation, makes significant improvements in reducing nitrogen loss.

It may be surprising that the natural vegetation and perennial agriculture in America's Pasture and Restoration Agriculture do not reduce nitrogen loss as quickly as may be expected for these land uses. A reason for the slowed progress is these land-use conversions took place on former cropland with an abundance of legacy nitrogen. The model results demonstrate that, even with this conversion, it will take a while for systems with perennial and natural vegetation to remove this excess legacy nitrogen.

The drawdown of nitrogen happens more quickly in Cropland Conservation because cover crops and saturated buffers are a quicker fix for this nutrient, and these practices are applied to more of the landscape in a relatively short period of time, compared to the other scenarios. So, the pace and scale of practice adoption play key roles. That said, beyond 2050, the other scenarios start catching up with Cropland Conservation.

Overall, the model results showcase the need for diverse and aggressive strategies to draw down both phosphorus and nitrogen levels. Each nutrient requires a different set of approaches.

Dietary Choices Will Ultimately Dictate Future Food Production

The Upper Mississippi River Basin is capable of producing a lot of food and biofuel, and it will be up to current and future generations to determine what crops to prioritize.

In the scenarios, dietary preferences and patterns largely dictate what foods farmers produce, which drives future food production. Changing diets are connected to the changes that occur on the landscape.

For example, in Restoration Agriculture, while there is less agricultural land by 2050, Americans consume less meat and dairy, which means food production is relatively unchanged between 2020 and 2050.

Changes in temperature and precipitation patterns will also impact food production. A more extreme climate trajectory will make it harder to achieve food production goals, no matter the changes that happen on the landscape. But if there is less warming in the future, it is possible to increase food production and make progress on the other goals.

For instance, in America’s Pasture, where the transformation is a shift toward grazing agriculture, if the climate is wetter but with less warming, food production increases the most of all the scenarios. This scenario with this climate also sees notable improvements in carbon storage in the ecosystem, perennial biomass for biodiversity, and sediment runoff reductions.

Sustaining Biofuel Energy Production Means Food, Water, and Ecosystem Tradeoffs

Perhaps not surprisingly, whether corn ethanol remains a significant part of the national energy portfolio determines how much biofuel can be produced into the future. It has a bit of an “on/off switch” effect—if society continues to prioritize biofuel, farmland can grow it.

However, the future of biofuel production will influence how much progress can be made toward goals for improving water quality, food production, and biodiversity.

Farmland continues to grow corn ethanol in two scenarios, Cropland Conservation and Hotspots for Transformation, due to demand for sustainable aviation fuel. But these scenarios see less improvement in food production, sediment loss, and phosphorus runoff than the other two. Cropland Conservation also has the smallest improvement in perennial biomass, a proxy for habitat, since so much farmland is used for producing corn ethanol.

Moreover, biofuel production cannot escape future climate impacts. The model results for Cropland Conservation show that, if the climate trends toward the hotter and drier end of the spectrum, biofuel production will not be as high as it could be under a less hot, but wetter climate.

We Can Improve Habitat, Regardless of the Climate

Perennial biomass served as a proxy indicator for habitat in the FEWscapes scenarios. Perennial biomass refers to the amount of perennial vegetation—often in the form of intact prairies, forests, or wetlands—on the landscape that can support a variety of plant and animal species.

All scenarios make big gains in perennial biomass, regardless of climate. In Cropland Conservation, the worst scenario for perennial biomass, its total quantity still increases by at least 40 percent from today.

This overall improvement for habitat across the scenarios is driven in part by the increase in atmospheric carbon, due to climate change, which increases the speed at which natural vegetation grows.

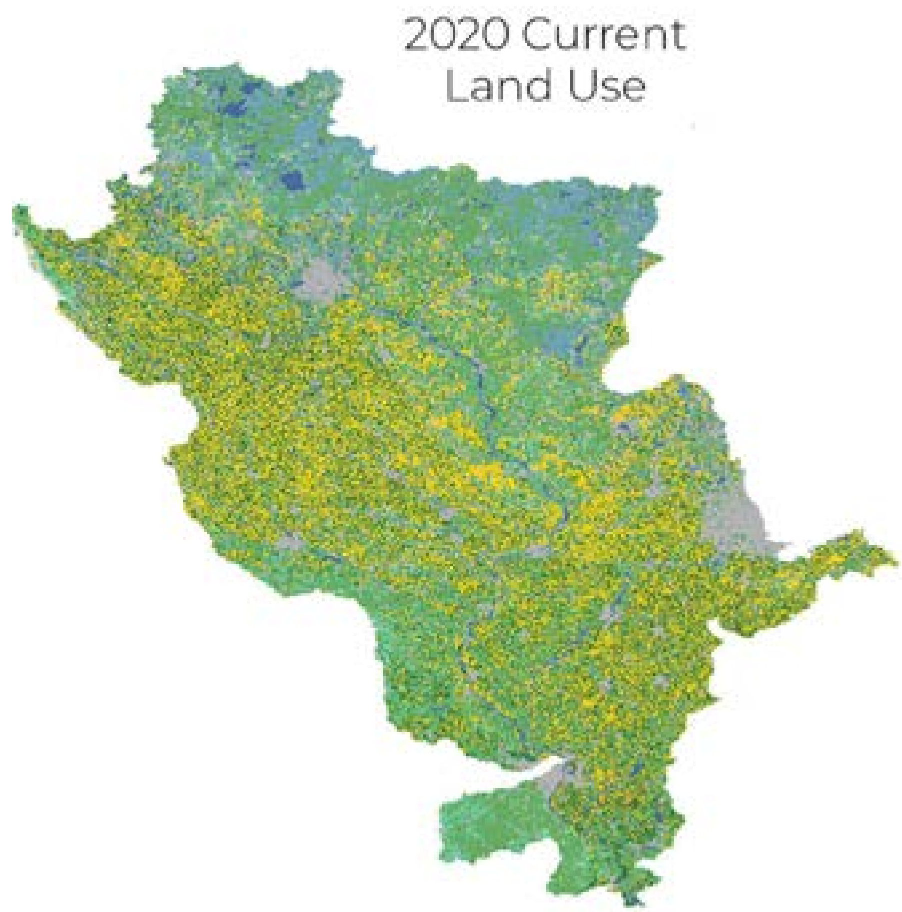
The bottom line of the perennial biomass model results is multiple approaches can make progress toward goals for improving biodiversity.

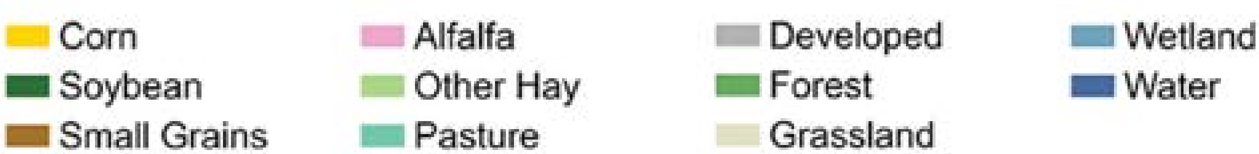
Appendices: Model Inputs

Appendix A: Land Use and Land Cover Inputs

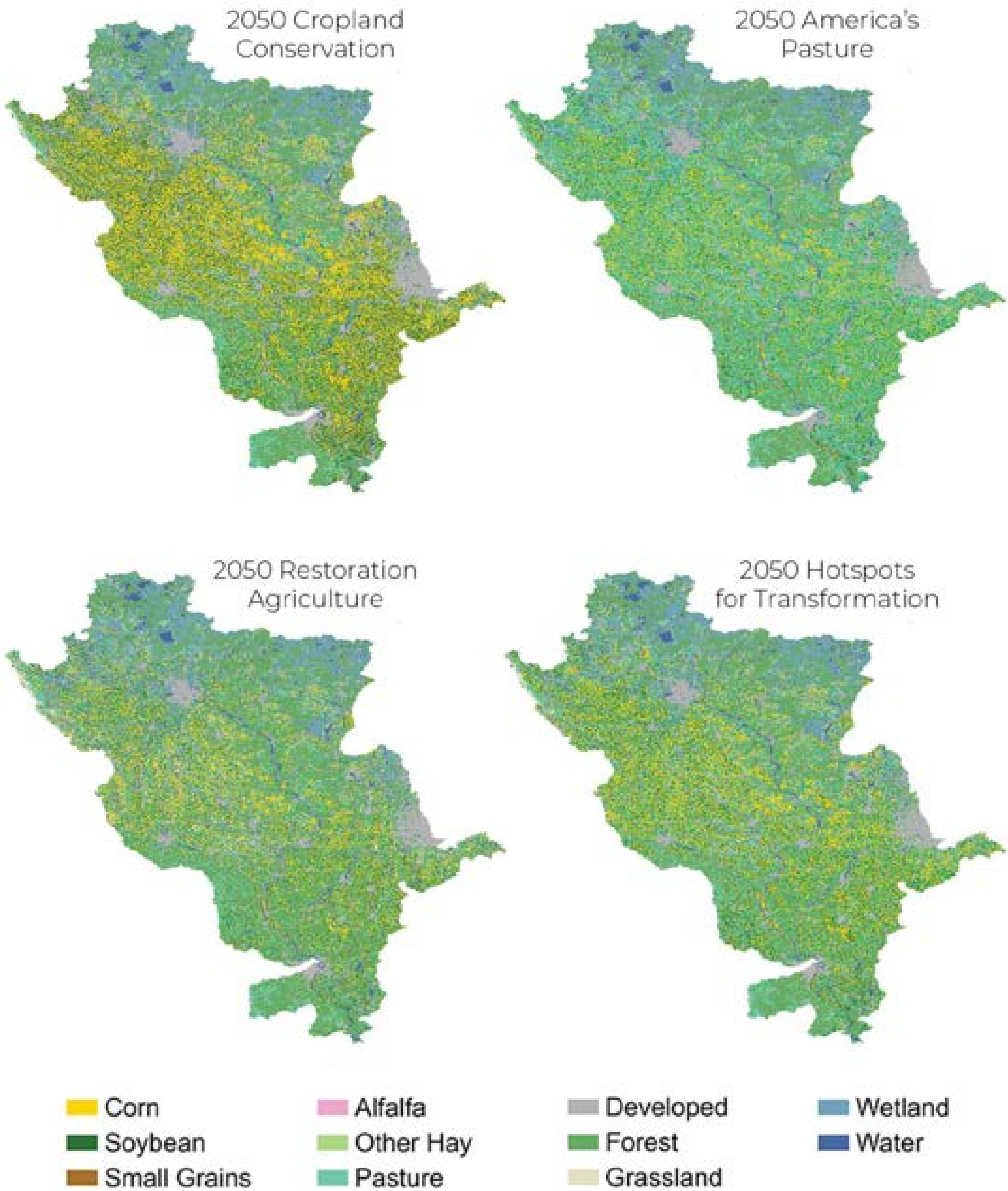
To project the impact of each imagined future on the Upper Mississippi River Basin landscape, the research team used land-use/land-cover maps to tell the models what happens on the landscape and where. The research team first produced a land-use/land-cover map that reflects land use as of 2020. Then, they created four projected future maps representing each scenario's future landscape. Each map is made up of square-kilometer "grid cells," the resolution at which the models operate.

The research team projected a gradual process of landscape change from the initial map to the four projected future maps, starting from the year 2026 and unfolding over the course of the following 20 years. Simulating landscape change in this way, instead of as single-step change, is more realistic, even though each of the scenarios represents profound transformations.





Landscape Change by 2050 in Each Scenario



Appendix B: Climate Inputs

The research team modeled each scenario under six different projected future climates, combining three different climate models with varying precipitation projections and two greenhouse gas concentration pathways. They used existing **downscaled global projections** provided by the Multivariate Adaptive Constructed Analogs (MACA), which we then further downscaled statistically to the Upper Mississippi River Basin.

The goal was to represent the range of possible future climates and account for the uncertainty inherent in climate modeling. To simplify results, this report includes only two of the following six model-plus-emissions pathways across: the wettest and least warm (GFDL 4.5) and the driest and hottest (HadGEM 8.5).

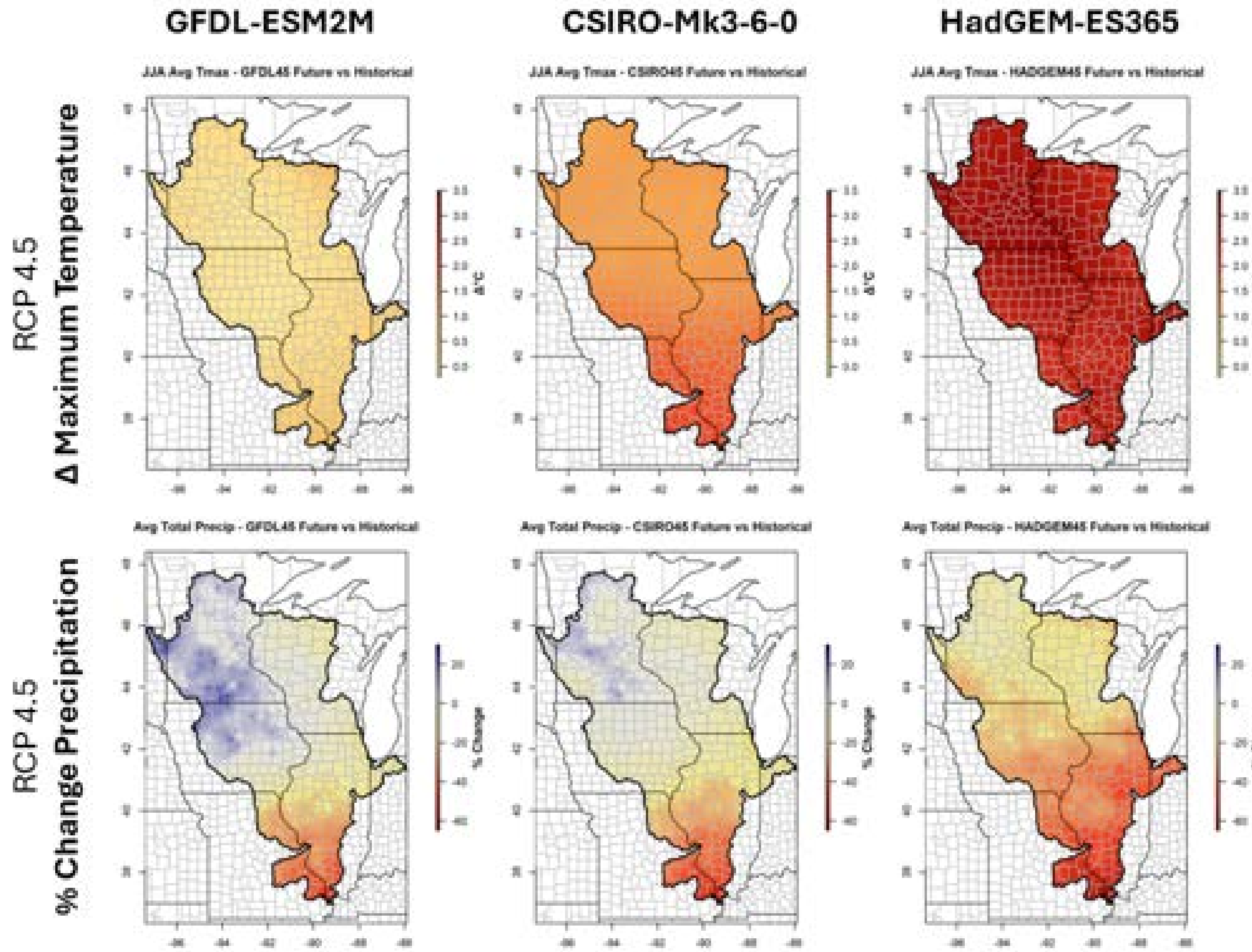
Precipitation and Temperature Projections

The research team chose three models from the **Coupled Model Intercomparison Project**, a compilation of top-tier climate models from around the world.

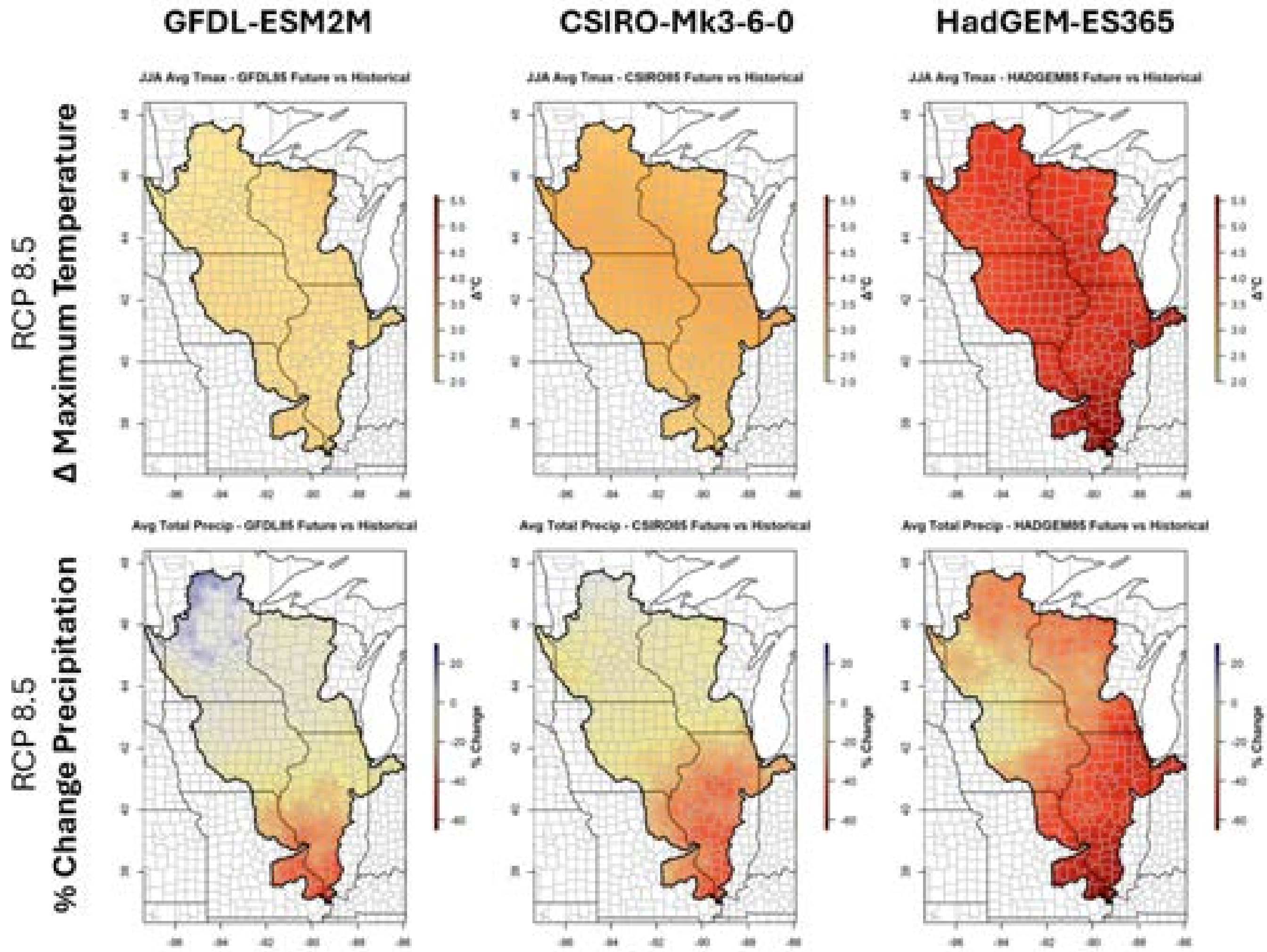
- HadGEM2-ES365 – projects dry and hot conditions for the Basin
- GFDL-ESM2M – projects wetter and less hot conditions for the Basin
- CSIRO-Mk3-6-0 – projects conditions that are somewhere in between HadGEM and GFDL

These three capture the breadth of variation among high-quality models. Together, they represent a wide range of plausible climate futures that policymakers and decision-makers might reasonably expect and prepare for. The figures on pages 57 and 58 show the climate projections used.

Climate model projections for mid-century summer precipitation and maximum temperature under RCP 4.5, a middle-of-the-road greenhouse gas concentration scenario.



Climate model projections for mid-century summer precipitation and maximum temperature under RCP 8.5, a high greenhouse gas concentration scenario.



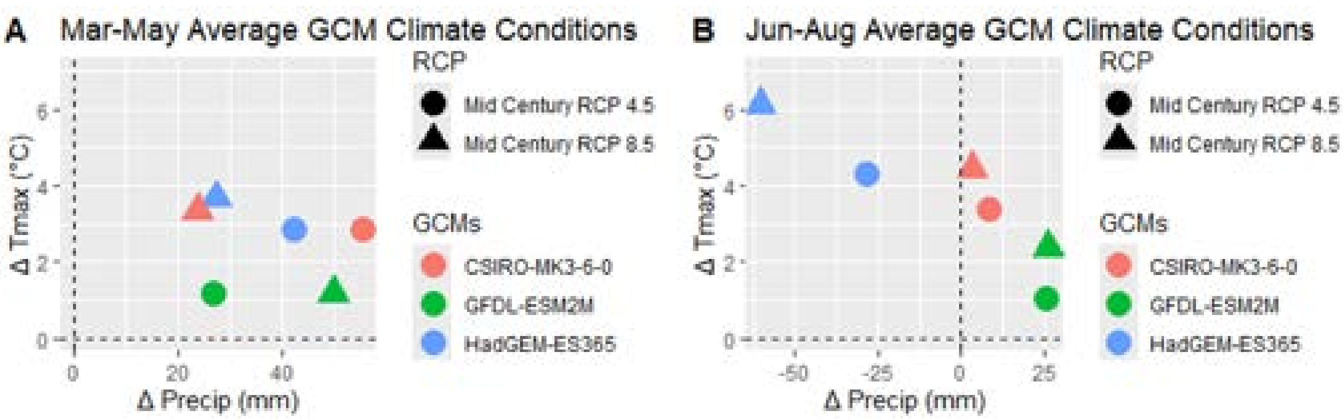
Greenhouse Gas Concentration Pathways

Each climate model relies on future greenhouse gas concentrations developed by the Intergovernmental Panel on Climate Change (IPCC) to generate its projections. How much greenhouse gases there are in the atmosphere depends on humanity's social, economic, and policy choices both now and in the future.

Representative Concentration Pathways, or "RCPs," provide different future trajectories of greenhouse gas concentrations. The two RCPs included in these scenarios are the following:

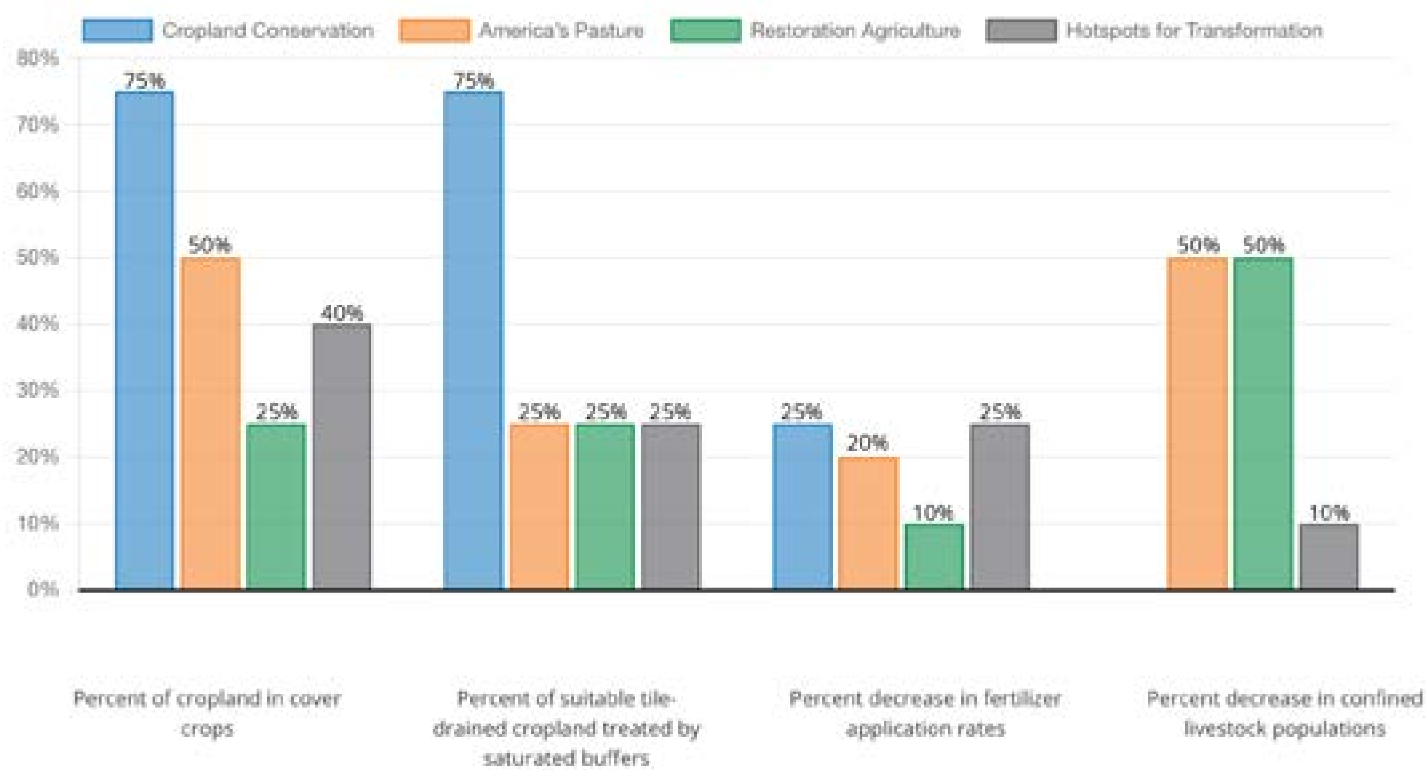
- RCP 4.5 is considered a "middle-of-the-road" pathway that is, arguably, close to our **current, real-world trajectory**. Cuts in carbon emissions are not aggressive enough to meet targets such as the Paris Climate Agreement's goal of limiting warming to 1.5 degrees Celsius.
- RCP 8.5 is a high-carbon pathway, representing continued growth in emissions and relatively little effort to control them. It's often used to represent "pessimistic" climate change trajectories.

A snapshot of how the six model-plus-emissions pathways compare during the spring and summer months.



Appendix C: Cropland Management Inputs

Cropland management inputs allow the models to project future crop yield, nutrient runoff, and other results. The research team modeled different percent changes for cover crop adoption, edge-of-field treatments (specifically saturated buffers on suitable tile-drained cropland), fertilizer application rates, and confined livestock populations as a proxy for manure production. The percent increases or decreases correspond with the dietary, policy, and other social changes that happen in each scenario. Those differences are shown in the figure below.



FEWscapes Scenarios: Aspirational Pathways for Food, Energy, Water, and Ecosystem Security in the Upper Mississippi River Basin to the Year 2050

Great change is possible for our landscapes. What future do you want?

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