SETTING AN AMBITIOUS SEQUESTRATION GOAL FOR CALIFORNIA'S WORKING LANDS:

ANALYSIS AND RECOMMENDATIONS FOR NET-NEGATIVE EMISSIONS BY 2030

JANUARY 2022

the climate center

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The Climate Center, January 2022

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Acknowledgements

The Climate Center produced this report in consultation with Dr. Jeff Creque and Torri Estrada of the Carbon Cycle Institute as senior advisors. Jock Gilchrist, Ellie Cohen, Katie Lyon, and Ann Hancock contributed writing and editing to the report. Expert review was provided by Dr. Tim Bowles, Dr. Keith Paustian, Dr. Elizabeth Porzig, Kat Taylor, Wendy Millet, Kevin Watt, and Megan Shahan. Review of this report does not constitute endorsement of its findings.

Executive Summary

Recent science shows climate change impacts pushing into "unprecedented territory" with potentially catastrophic impacts unless we act decisively now. To maintain the best chance of staying below the 1.5C threshold of dangerous warming, dramatic greenhouse gas emissions cuts coupled with significantly scaled up carbon dioxide removal from the atmosphere are required.

Companies, governments, and other actors have proposed technological methods for carbon dioxide removal, but in comparison, carbon sequestration on natural and working lands is more affordable, immediate, scalable, and proven. It also delivers a broad suite of benefits beyond climate: water security, air and water quality, wildfire resilience, and biodiversity. Many of the associated practices could also reduce the damaging impacts of industrial agriculture. These impacts most strongly harm disadvantaged communities, which are defined by the state's CalEnviroScreen tool as communities ranking in the top 25% for exposure to pollution and population characteristics that make them especially vulnerable to pollution's impacts. We use the term somewhat more broadly to include low-income and frontline communities who have experienced historic environmental inequities.

This analysis shows how California can set and achieve an ambitious carbon sequestration goal for its working lands (including some urban lands). By leveraging proven techniques, the state could sequester up to 289 million metric tons (MMT) of carbon dioxide equivalents (CO_2e) between now and 2030, and up to 103 MMT CO_2e each year thereafter, assuming optimized, best-case conditions. Barriers to achieving such a goal are not biophysical but social, political, and financial. Our calculations rely on peer-reviewed publications and data in the COMET-Planner tool (NRCS, 2022).

The practices assessed to reach 103 MMT CO_2e per year by 2030, in MMT CO_2e per year, are:

- cropland compost (54)
- pastureland compost (11.55)
- rangeland compost (3.52)
- avoided nitrogen fertilizer (7)
- agroforestry (15.20)
- prescribed grazing (0.22)
- riparian restoration (2.37)
- urban greening (5.95)
- roadside buffers (2.75)

Implementation of these practices on millions of acres in California could remove carbon from the atmosphere and increase soil water holding capacity by tens to hundreds of billions of gallons. Coastal and freshwater wetlands, near shore habitat, and forest lands offer significant additional sequestration potential, but are not included in this analysis.

The primary focus of this report is to examine the climate imperative, and biological potential, for working lands to sequester carbon at speed and scale. In the interest of operationalizing these findings, it concludes with policy and program recommendations for developing mechanisms to support such a magnitude of working lands sequestration. Recommendations include increased funding for state carbon sequestration programs, support for a large and well-trained network of technical assistants and on-the-ground practitioners, better end-market opportunities for carbon sequestering products coming from California working lands, improved compost infrastructure and regulation, and others.

All of these policies must be designed to address the needs of frontline populations, especially farmworkers and lower-income communities. Their full participation is key to the design, advocacy, and implementation of successful natural and working lands sequestration policies and programs.

By scaling up carbon sequestering practices between now and 2030, and maintaining them thereafter, California's working lands could absorb hundreds of millions of tons of carbon. In so doing, California can mitigate climate change and provide a broad suite of benefits to all Californians. The urgency of the climate crisis demands nothing less.

Introduction: The Urgent Need for Nature-Based Carbon Dioxide Removal

> *"California's lands are losing carbon, with an estimated net loss of approximately 170 million metric tons (MMT) of carbon from 2001–2014. This loss of carbon is equivalent to a cumulative 630 MMT CO2e of sequestered carbon removed from the land over the same 13-year period. The majority of these losses are due to wildfire." (ARB 2019)*

As outlined in the IPCC's Sixth Assessment Report (2021), and evidenced by symptoms of global climatic disruption observed in recent months, we must act immediately to avert catastrophic climatic change. Critically, while carbon dioxide removal strategies alone are not sufficient to address the global crisis, "all pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 gigatons of carbon dioxide (GtCO2) over the 21st century" (IPCC 2018). These approaches grow even more urgent in light of recent science that says the atmosphere could cross the 1.5°C threshold of dangerous warming as soon as 2027-2030 (Xu, Ramanathan, and Victor, 2018; IPCC, 2021).

Even the modest California Air Resources Board (ARB) goal of 15-20 MMT captured by natural and working lands (NWL) cannot be met if we continue to delay implementation of known practices. These practices that have been implemented and validated since at least the Dust Bowl era (Figure 1) – and even longer by Indigenous land stewards – to increase carbon storage in soils and vegetation on working lands (USDA, 1938). These same practices provide multiple additional benefits. As the West enters a multi-decade megadrought made severe by climate change, these practices will improve water retention and reduce irrigation demand, improving societal resilience to such extreme conditions. To achieve net negative emissions for California by 2030 – The Climate Center's target (Kammen. et al., 2021) – we must significantly scale up known carbon-beneficial land management practices on natural and working lands immediately.

Figure 1. Oklahoma 1935, or California, 2035?

Photosynthesis from forests, oceans, and other ecosystems currently removes from the atmosphere roughly 50% of fossil fuel carbon dioxide emitted by human activity each year (NOAA, 2021). Enhancing CDR through improved management of our NWL offers the single largest and most practical pathway to draw down atmospheric carbon as required to secure a stable climate. In addition to sequestering carbon, stemming the loss of carbon from natural systems is another essential climate mitigation task. Forests and soils from the Amazon to California and beyond, for example, have crossed from being carbon sinks to sources, a trend that must be reversed (Henson, 2021; Dass, Houlton, Wang, & Warlind, 2018; Wang, Zhuang, Lähteenoja, Draper, & Cadillo-Quiroz, 2018).

Techniques that increase photosynthetic capture of CO_2 and reduce losses on working lands can be deployed affordably, immediately, and at scale to preserve natural water supplies; enhance resilience to wildfire, drought, and heat extremes; increase food security; improve biodiversity and ecosystem resilience; and achieve myriad other benefits for both humanity and the environment. This puts it in contrast to approaches like geoengineering, with its associated uncertainty and risks of negative environmental impacts, and technological CDR[1] such as direct air capture, which are nascent, unscaled, expensive, and energy intensive. Other anthropogenic climate-altering effects also underscore the urgent need for action: for example, ozone formation from human-made substances can inhibit plant photosynthesis and further weaken agricultural productivity.

Governor Brown's Executive Order B-55-18,[2] "To Achieve Carbon Neutrality," notes: "the achievement of carbon neutrality will require both significant reductions in carbon pollution and removal of carbon dioxide from the atmosphere, including sequestration in soils, forests, and other natural landscapes." The Order establishes a new statewide goal to achieve carbon neutrality as soon as possible and no later than 2045 and to maintain net negative emissions thereafter. The order requires the state Natural Resources Agency (CNRA), the Environmental Protection Agency (CalEPA), the Air Resources Board (ARB) and Department of Food and Agriculture (CDFA) to, "include sequestration targets in the Natural and Working Lands Climate Change Implementation Plan consistent with the carbon neutrality goal," and further notes: "All policies and programs undertaken to achieve carbon neutrality shall seek to improve air quality and support the health and economic resilience of urban and rural communities, particularly low-income and disadvantaged communities." These are lofty and laudable goals which remain unmatched by effective state action.

Governor Gavin Newsom took this target a step further by directing ARB to evaluate pathways for the state to achieve carbon neutrality a decade earlier, by 2035 (2021). Achieving this accelerated timeline requires not only a rapid reduction in the burning of fossil fuels, but a significant increase in the removal of carbon from the atmosphere. Managing NWL in ways that both improve ecological outcomes and optimize for CDR will be an essential element of the path to carbon neutrality and net negative emissions.

Simultaneously, wildfires made worse by climate change are rapidly releasing carbon from terrestrial stocks at an increasing rate. Over 4.2 million acres burned in CA in 2020, making it the largest fire season in modern California history (CAL FIRE, 2020). From 2000 to 2019, wildfires in California released an annual average of 14 MMT CO2. The 2020 fire season, by comparison, is estimated to have released almost 110 MMT CO2 from California's natural and working lands (CARB, 2020).

In the face of recent and ongoing catastrophic fires across the state, achieving the even more ambitious goal for California of carbon neutrality by 2030 and net-negative emissions thereafter renders imperative the full and immediate engagement of the state's working lands – including forests, farms, rangelands, wetlands, and urban environments – in a major, ongoing role as carbon sinks. Nothing short of a full court press on the part of all responsible state agencies, fully engaged with technical service providers, NWL managers, and a significantly expanded workforce on the ground, has any hope of achieving this objective. As evidenced by recent shortages of firefighting capacity due to COVID-19 impacts,

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[1] The Climate Center does not view conventional carbon capture and storage (CCS) as a form of CDR. It (in theory) lessens carbon pollution from fossil fuel-based electricity but does not remove carbon from the atmospheric pool.

[2] Governor Newsom's recent Executive Order reiterated the State's goal for carbon neutrality.

mobilizing the skills, resources, and personnel to realize this response will be extremely challenging. Yet it must be done – and in a manner that increases equity – if we are to have any near-term hope of achieving carbon neutrality for the state, let alone slowing or stopping the now accelerating pace of global climate change.

To prevent the worst consequences of climate change and catalyze accelerated climate action nationally and globally, California must pursue ambitious methods to equitably achieve carbon neutrality by 2030 and sequester as much atmospheric carbon as is possible and sustainable in NWL. The Climate Center's Climate-Safe California Campaign is a set of just and equitable policies that lay out a pathway to net negative emissions by 2030. The campaign sets aggressive targets in every sector, not just NWL, to inspire action commensurate with the urgency of the rapidly worsening crisis. As Professors Dan Kammen and Manuel Pastor wrote in the *San Francisco Chronicle* (2021):

> California has the solutions to our climate crisis at hand. Policies to speed up the transition from fossil fuels to clean energy — including phasing out gas-powered vehicles and offering credits to home and business owners who purchase energy-efficient technologies — will vastly reduce the amount of pollution we release each year. At the same time, scaling up nature-based carbon sequestration techniques and protecting vital ecosystems like forests and wetlands will begin to draw down some of the carbon already in the atmosphere.
>
> This is how we get to carbon negative by 2030.

The Climate Center recently modeled a pathway to carbon neutrality by 2030 (Kammen, et al., 2021). More and more academics, scientists, and journalists have called for a dramatically accelerated carbon neutrality goal for the state from 2045 to 2030, in line with Climate Safe California recommendations (Roth, 2021). Still, many who are accustomed to expecting a slower pace of change distrust that the state can meet such an ambitious target. The Climate Center holds that such goals are possible – even if this possibility hinges on a never-before-seen level of policy coordination and resource deployment. Yet nothing short of this scale of action is required to meet the demands of the climate crisis, the quickening pace of which continues to confound even our best climate models (Watts, 2021).

This paper aims to quantify an aggressive sequestration target to contribute to a carbon negative future. Our analysis focuses on arable lands (cropland, pastureland, and rangeland), as well as some urban spaces and roadside strips. It excludes other land types that could potentially contribute significant quantities of carbon sequestration, like forests, wetlands (non-riparian), and other habitat types. It establishes an annual sequestration goal that is within natural and scientific limits for soil carbon capacity, but would require an unprecedented activation of political, social, and financial resources to achieve it. The state's coastal and freshwater wetlands, near shore "blue carbon," and forest lands offer significant additional sequestration and mitigation potential but are not included in this analysis.

As with other tenets of Climate Safe California, the sequestration targets discussed below are challenging, but not impossible – and the distinctions between those two words could make all the difference in creating a climate-safe future.

Scaling Agricultural Conservation Strategies across California

Some soils in the California Central Valley used to be high in soil organic matter. These lands were once comprised of millions of acres of wetlands and marshes which have shrunk by an order of magnitude since the 1800s (Frayer, Peters, & Pywell, 1989). The present-day Bakersfield area was once home to Tulare

Lake, the largest lake west of the Mississippi before it disappeared (Naida Blevins, 2002). The nutrient-dense and carbon-rich soils that were left behind contributed to California's agricultural productivity. There is reason to believe that these soils could replenish their carbon stores on the order of millions of tons of carbon – much of which have been lost from soils in just the last century.

Our analysis suggests this goal can be realized (and exceeded) through implementation of a comprehensive statewide strategy that engages, over time: 1) most of the state's 20.4M acres of arable land,[3] 2) at least 3.5M acres of California rangelands,[4] and 3) 50% of the state's 400,000 miles of highway rights of way and 1M acres of riparian area.[5]

In an optimized scenario, this analysis yields a potential to sequester up to 289MMT CO2e in the working land sector by 2030. This could be sustained beyond 2030 at a rate of up to 100 MMT *annually* for one to two decades or more by continuing to deploy practices and engage additional acreage under the scenarios summarized below in Table 1 (and further described in "Summary of Pathways" below). Synergies between practices could produce even higher sequestration rates when practiced in conjunction over time (DiVittorio, Simmonds, & Nico, 2021).

Practice	Annual Acreage (new)[6]	Rate (MT CO_2e/ac/yr)	Annual MT CO_2e (new acres)	2030 Acreage Total	Cumulative 2021-2030 (MMT CO_2e)	2030 Annual Rate (MMT CO_2e)
Rangeland compost	352,000	1	352,000	3,520,000	19.36	3.52
Pasture compost	1,155,00	1	1,155,000	11,550,000	63.53	11.55
Cropland compost	1,200,000	4.5	5,400,000	12,000,000	54.00	54.00
Agroforestry	760,000	2	1,520,000	7,600,000	83.60	15.20
Riparian restoration	160,000	1.48	236,800	1,600,000	13.02	2.37
Prescribed grazing	436,000	0.05	21,800	4,360,000	1.20	0.22
Urban Forestry	147,258	4.04	594,922	1,472,580	32.72	5.95
Roadside forest buffers	155,152	1.77	274,619	1,551,520	15.10	2.75
N fertilizer avoidance	1,600,000	0.44	704,000	16,000,000	7.04	7.04
Selected totals					**289.57**	**102.59**

Table 1. Carbon dioxide removal through working land sequestration to achieve 100MMT CO_2e/year by 2030.

Nature-based sequestration of this magnitude would require an immense and coordinated effort on the part of land managers, policymakers, and state agencies at a level that has not been seen before. Rapid,

[3] This figure refers to California's cropland and pastureland (NASS, 2019). The various estimates for California's arable land range between 20 and 25M acres.
[4] This equates to over 6% of California's 57M acres of rangeland. This rangeland estimate refers to California's grasslands, chaparral, oak woodlands, and related non-agriculturally managed lands (UC Rangelands, 2016; Filmer, 2015).
[5] This assumes roughly 1% of the state land area (1M acres) is riparian today and could benefit from restoration efforts (see Kattelmann and Embury, 1996; State of California, 2016; and Matzek et al 2020).
[6] Averages may include a smaller amount of new acreage in early years and a larger amount in later years of the timeframe.

large-scale investment in the infrastructure that would make possible attaining such CDR is a prerequisite to the deployment of these practices. But this is the chief barrier – 100MMT of annual sequestration is not beyond a biophysical limit of California's soils. Impediments to this goal are political, social, and financial. Analysis below explores this idea in more detail.

Of the 100MMT annual sequestration potential assessed in this report, over 67% of this benefit derives from ongoing compost applications on the state's rangelands, croplands, and pastures, and 23% percent from agroforestry and afforestation practices on riparian areas, rural and urban lands, and along state highways, with the remainder derived from increased photosynthetic capture of carbon through enhanced soil and vegetation management using numerous strategies and avoided nitrogen fertilizer production and use.

Several elements of Table 1 warrant further discussion. First, not all recommended practices would occur on "unique" acres – many of them will be "stacked" on the same acres. For example, prescribed grazing and rangeland and pasture compost can co-occur; even prescribed grazing and riparian restoration can as well (Nelson, 2020). As such, summing the acreage shown in the table could be misleading.

The bulk of climate benefits in the table are accomplished via compost: both compost application and avoided N fertilizer use due to compost substitution. Rates of carbon sequestration from compost are derived from the COMET-Planner tool, which utilized numbers produced by ARB and is used by the California Department of Food and Agriculture to assess its Healthy Soils Program (NRCS, 2022). Some scientists assert that COMET-Planner's sequestration estimates for compost are too high because they assume an inflated avoided-GHG figure. They may also, however, assume a lower compost application rate than is desirable and beneficial. The COMET-Planner compost figures can thus be seen as an estimate involving a fair degree of uncertainty. There is also ambiguity as to the compost decomposition rate, and thus the sequestration rate, over decade-or-longer timeframes. COMET-Planner uses a 3-year time horizon for its sequestration rates for compost, while over 10 or more years, stocks from compost application that are assumed to be stable in soils may decompose. This could lead to overestimated rates in COMET-Planner. The compost sequestration rates are likely what could be observed under optimized conditions and represent a best-case scenario.

Given the heavy reliance on compost application, there is a need to determine where the compost feedstock and compost itself will originate. According to Lawrence Livermore National Laboratory's (LLNL) *Getting to Neutral* report, there will be 54 million bone dry metric tons of biomass available annually statewide in 2025 from agricultural, municipal, forest, and anaerobic digester sources (Baker, et al., 2020). This could produce over 20 MMT of compost annually. State infrastructure needs to expand to process biomass and produce this much compost, with consideration of pollution impacts on frontline communities, but feedstock availability is not the limiting factor.

The data in Table 1 represent a pathway to significant nature-based CDR in California. While we use the best available data, there is uncertainty inherent in attempting to make such calculations. The field of soil science is rapidly evolving and zeroing in on ever more precise numbers for natural sequestration. While 100 MMT CO_2e of annual sequestration is possible under the right conditions, even half of that would be the equivalent of removing 12% of California's annual emissions at 2019 levels, or of taking 11M cars off the road (EPA, 2021).

Carbon Sequestration through Statewide Soil Organic Matter Increase on Arable Lands

In California's deepening drought, every drop of water that can be retained in natural lands and aquifers is precious. Water (via precipitation or irrigation) is a prerequisite for soil carbon sequestration, so drought could make sequestration targets harder to achieve. The Sustainable Groundwater Management Act could also result in soil carbon losses as irrigation at some sites is removed. At the same time, this makes it even more important to increase soil health and soil water retention efforts as soon as possible, because these measures can ameliorate impacts of drought and lost irrigation. As lands are managed for soil health and carbon sequestration, SOM and water retention increase.

The USDA-NRCS has suggested 5% SOM as an indicator of a "healthy" soil (though varies with geographic factors for climate and soil type). Assuming current average SOM content of 1.5% in the plow layer of the state's arable soils, an increase in SOM of 3.5%, or roughly 35 tons per acre, would be needed to raise the state's approximately 20.4M acres of arable soils to 5% in the plow layer only. This is 714M short tons of SOM. Given that about half of SOM is Soil Organic Carbon (Pribyl, 2010), this is 357M short tons of C, representing the potential to beneficially move 1.19 *billion* MMT CO2e from the atmosphere to the soil.

A 3% increase in SOM in the plow layer alone, across the 47M "working land" acres of the state (Flint et al 2018) represents roughly 1.4 Billion tons of SOM, or 705M tons of soil organic carbon.[7] This amount of SOC represents 2.35 *billion* MT CO2e (2.35 Gigatonnes or 2.35 Petagrams) removed from the atmosphere through plant photosynthesis.[8]

A mere 1% increase in SOM across the state's 20.4M arable acres alone would represent 340MMT CO2e[9] transferred from the atmosphere to the state's working land soils. Note that the carbon costs associated with achieving these ambitious goals are not included here but are expected to be less than 20% of the total carbon gains resulting from these efforts (DeLonge et al, 2013). These thought experiments vary in their realism but illustrate the enormous carbon sequestration potential when managing for even small SOM increases at scale across California.

Significant Water Benefits from Agricultural Soil Organic Carbon Increases

The California Natural Resources Agency (CNRA) 4th Climate Assessment Report (Flint et al 2018) highlights the relationship between soil organic carbon (SOC) (as soil organic matter) and the hydrology of the state's working lands. The report models relationships among soil organic matter (SOM), groundwater recharge, net primary productivity and climatic water deficit, and shows that increasing SOM concentration by as little as 3% across the state's 47M acres of working lands would result in an annual hydrologic benefit of at least 4.7 M acre-feet of water, equivalent to 1.53 *trillion* gallons of water, or Shasta Lake when at capacity. An increase in soil water could allow farmers and water managers to adjust irrigation practices to reduce pressure on reservoirs and groundwater. As noted in the report:

> Increased soil organic matter can be achieved in multiple ways to increase soil water-holding capacity, forage and crop yields, increase baseflows and aquifer recharge, reduce flooding and erosion, increase carbon sequestration, and reduce climate-related water

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[7] A 1% increase in SOM is roughly 10 short tons per acre or about 5 short tons of SOC per acre (Pribyl 2010). 3 x 5 x 47M = 705M tons C.

[8] 705M short tons x 0.909 = 640MMT C, and 640MMT C x 3.67 = 2.35 Billion MT CO_2e.

[9] 1 x 5 x 20.4M x 0.909 x 3.67 = 340MMT CO_2e

> deficits, thereby developing hydrologic resilience to climate change while simultaneously reducing atmospheric greenhouse gases.

Importantly, decreasing climatic water deficit can be expected to decrease the flammability of biomass (though total biomass production may increase).

Comparing the 2030 Working Land Sequestration Timeline to the Status Quo

While this analysis suggests a potential to sequester up to 103 MMT CO_2e annually in working lands, current negative emission scenarios significantly underutilize NWL. *Getting to Neutral* found that achieving carbon neutrality by 2045 will require the removal of 125 MMT CO_2 annually. The report breaks down this 125 MMT into three categories: natural and working lands (25 MMT/yr), conversion of biomass (84 MMT/yr), and direct air capture (16 MMT/yr) (2020). It considers several "natural solutions" as essential components toward achieving this goal, including reforestation, tidal and marsh restoration, freshwater wetland restoration, grassland restoration, changes to forest management, and soils (Table 2).

Strategy	Negative Emissions Potential in 2045 (MMT CO_2e/yr)	Negative Emissions Potential in 2030 (MMT CO_2e/yr)
Restoration/Urban Forestry	Reforestation: 4.9	Urban Forest: 5.95 Roadside Forest Buffers: 2.75
Wetland/Riparian Restoration	Tidal Marshes: 0.9 Freshwater Wetlands: 0.2	Riparian Areas: 2.37
Grassland Restoration/Prescribed Grazing	0.1	0.22
Changes to Forest Management	15.5	15.20
Increasing Soil Organic Carbon	Soils: 3.9	Rangeland Compost: 3.52 Pasture Compost: 11.55 Cropland Compost: 54.00 N Fertilizer Avoidance: 7.04
Total Natural Solutions	**25.5**	**102.59**

Table 2. Negative emissions potential from NWL. The 2045 Timeline is adapted from Getting to Neutral report from LLNL. The 2030 timeline is adapted from analysis by the Carbon Cycle Institute.

Getting to Neutral identifies a pathway by which the state could achieve carbon neutrality by 2045, with NWL sequestrations amounting to only 25 MMT of total annual carbon sequestration. These estimates are based primarily on a 2017 study conducted by Cameron and colleagues. While Cameron et al. considered a wide range of natural solutions, it also left several out. These limitations are highlighted below (emphasis added):

> This study considers only activities that presumably provide ecosystem cobenefits to natural land cover types and, as such, **is a conservative estimate of the full mitigation potential of land-based interventions**. Modeling a full set of agricultural management practices, for example, is beyond the scope of this study but represents a complementary set of interventions to those considered here. Activities that may promote increased carbon sequestration in agricultural soils, limit methane and N2O emissions in crop systems, and adapt grazing practices to promote sequestration **were not included here but may contribute substantial additional reductions**.

Getting to Neutral presents valuable insights into several NWL sequestration opportunities, but it leaves out the vast potential of cropland and pasture soils to sequester on the order of 65.55 MMT CO2e annually. The 2017 Cameron et al. study that formed the basis for this report's NWL analysis similarly does not discuss nitrogen fertilizer avoidance and its potential to contribute 7.04 MMT CO_2e of annual negative emissions. Given the discrepancies in CDR potential across approaches in *Getting to Neutral,* the report favors technological, rather than a biological, solutions to a biological problem.

Further, land-based carbon solutions may offer a better chance than technological, capital-intensive ones for meeting climate goals equitably. A report by The Nature Conservancy demonstrates the potential for nature-based solutions to provide social co-benefits on millions of acres statewide to disadvantaged and low-income communities in the form of more open space, better air and water quality, expanded urban forests, and more (2020).

This complementary analysis suggests that achieving a 2045 net-negative carbon emissions scenario requires far less than the full sequestration potential of NWL. If the full NWL carbon sequestration potential were harnessed, achieving carbon neutrality in the state by 2030 becomes an attainable goal.

Summary of Pathways

The potential CDR benefits of implementing several NWL strategies are outlined below.

Rangeland Compost Application

Assuming 3.52M acres of the state's rangelands (57M acres, 6.2% of total acres) are suitable for a single application of compost, leading to enhanced capture of at least 1 MT CO2e per acre per year for 25 years (Ryals et al 2015, Ryals and Silver 2013), engaging 352,000 acres annually would result in 352,000 MT CO2e/yr in year one, increasing annually to an estimated cumulative total of 19.36 MMT on 3.52M acres by 2030.

Recommendation: Engage 352,000 new rangeland acres annually, achieving 3.52M acres by 2030.

Pastureland Compost Application

Assuming engagement of 1.155M new acres annually in this practice, 11.55M acres could be treated with a single application of compost by 2030, sequestering an estimated 63.53 MMT CO2e. All acres of the state's managed grasslands and pastures (as distinct from rangelands) would be treated with 5.3 dry tons/acre, sequestering 1 MT/CO2e/acre/yr (CDFA COMET-Planner).

Recommendation: Engage 1.155M new pastureland acres annually, reaching 11.55 acres by 2030.

Cropland Compost Application

Applying a minimal amount of compost (5.3 dry short tons per acre) annually – well below accepted agronomic maximums[10] – on 1.2M new acres per year from 2020 would yield an annual sequestration rate of 4.5 MMT CO2e/yr *each year compost is applied* (CDFA/ARB QM) and engage 12M acres, sequestering 54 MMT CO2e by 2030. Engaging all of the state's 10.4 million irrigated acres by 2045 would result in an estimated CDR of 4.5 MT CO2e/acre each year compost is applied, or up to 46.8 million metric tons of CO2e by 2045 (CDFA COMET-Planner). In addition, at 1.5% N, this amount of compost represents up to 827,000 short tons of organic N each year. This exceeds the quantity of synthetic N imported into the state each year (CNA 2015), and represents the *recycling of existing N*

[10] The U.S. Environmental Protection Agency has cited application rates as high as 100 to 200 tons per acre in scenarios where compost is used for erosion control in high rainfall areas. See Table 2, https://www3.epa.gov/npdes/pubs/aashto.pdf.

resources within the state, rather than new inputs. The avoided CO2e emissions associated with 827,000 short tons (750,000 MT) of avoided N fertilizer production and use are estimated to be up to 11.7 MMT CO2e,[11] for a total benefit from compost use on cropland of 58.5 MMT CO2e/year by 2045.

Recommendation: Engage 1.2M new acres annually through 2030 and 400,000 new acres per year through 2045, and reduce or eliminate synthetic N use on all compost-treated acreage.

On a per acre basis, 5.3 short tons of compost represents 5.3 x 0.015 x 0.907 = 0.07MgN = 159 lbs N/acre. In organic form, only 10-25% (16-40 lbs) of that N is assumed available each year. As SOM increases over time, greater quantities of N will also be available. At full availability, 159 lbs of avoided N/acre represents 1.1 Mg CO2e avoided per acre (159/2200 x 15.6 = 1.1). This analysis assumes an average of 70 lbs/acre of avoided N (0.44MgCO2e/acre/yr).

Agroforestry

Assuming adoption of agroforestry practices on 7.7M acres (~10% of the state's 77.4M acres of crop, pasture, and rangelands), and a modestly enhanced sequestration rate of 2 MT CO2e/acre/yr, an estimated 1.52 MMT CO2e could be sequestered annually. If 760,000 acres were engaged annually through 2030, 83.6 MMT CO2e would be captured by 2030, while engaged acreage would continue to accrue carbon.

Recommendation: Engage 760,000 new acres annually through 2030.

Riparian Restoration

The carbon sequestration potential associated with restoration of 1.6M acres of riparian systems alone is very conservatively estimated to be at least 2.37 MMT CO2e/yr given a rate of 1.48 MT CO_2e/ac/yr (Matzek et al 2020). If wholesale restoration efforts were initiated on all available Central Valley riparian acreage by 2030, at least 13 MMT CO2e would be sequestered by 2030.

Recommendation: Engage at least 160,000 riparian acres annually through 2030; identify additional riparian restoration opportunities and initiate projects across all the state's Resource Conservation Districts by 2035.

Prescribed Grazing

Prescribed grazing can be an effective strategy to increase carbon capture on rangelands and pastures. Rates of accumulation between 0.005 to 3.0 MT CO2e/acre/year have been reported in the literature (COMET-Planner; Conant et al, 2017; Teague et al 2016). If carbon capture on just a portion of the state's 57 million acres of grazed rangeland were increased at the rate of 0.05 MT CO_2e/ac/year through prescribed grazing, engagement of 436,000 new acres annually would sequester 21,800 MT CO2e annually. Maintenance on all engaged acres adds to a cumulative 4.36M acres capturing 1.2 MMT by 2030.

Recommendation: Engage 436,000 new acres of rangeland and pasture annually in targeted grazing for enhanced carbon capture through 2030 and beyond.

Roadside Forest Buffers

Roadside Forest Buffers have significant carbon capture potential in California. Using Riparian Forest Buffer (CPS 391) values for Merced County from COMET-Planner (1.77 MT CO_2e/acre/yr), carbon

[11] Every metric ton of nitrogen spread in the form of fertilizer is responsible for 10.5MgCO2e of emissions in the field (67%) and 5.1MgCO2e during its production (33%) (Foucherot and Bellassen 2011).

sequestration potential associated with planting of trees along the state's 400,000 miles of roadway (roughly 800,000 miles of roadside) was estimated. Assuming 50% of the state's 800,000 miles of roadside are available for planting and a roadside forest buffer width of 40 feet, 1.94M acres of such buffers could be planted. If 155,152 acres are planted annually that sequester an additional 274,619 MMT CO2e each year, 1.55M acres would be engaged by 2030, sequestering over 15MMT CO2e through 2030 and 2.75MMT CO2e annually thereafter.

This strategy offers significant job opportunities to the state, and has the potential to at least partially fund itself through the production of hardwood and other merchantable timber under both short and long-term harvest scenarios. Roadside buffers can also serve as infiltration areas for roadside runoff, converting polluted storm water runoff to "green water" through absorption by soils and the growing roadside forest buffer vegetation. Note that the proposed 40' buffer width is extremely conservative.

Recommendation: Engage 155,000 new acres of roadside buffer plantings annually through 2030 and beyond.

Reduction in Use of Nitrogen Fertilizer

As noted above, there is potential to significantly reduce synthetic N use in the state through recycling of organic nitrogen sources, avoiding an estimated 11.7 MMT CO2e annually and significantly reducing the associated burden on the state's ground and surface waters and air quality, including the potent GHG N2O (Rosenstock et al 2013, CNA 2015, Almaraz et al 2018).

Recommendation: see cropland compost recommendations above.

Urban Forestry

Table 3 shows annual rates of carbon sequestration by urban forests in CA (Nowak and Crane 2002). California's urban area is 6.4% of the state's land cover at almost 6.8M acres. Urban area has tree cover of roughly 10.9%. At this level of urban forest cover, roughly 3 MMT of CO2e is sequestered annually and 30 MMT CO2e would be sequestered by existing urban forests between 2020 and 2030. A doubling of urban tree cover from 2020 to 2030, from 10.9% to 21.8% of urban land area (from 736,290 acres to 1.47M acres), could lead to cumulative sequestration of over 32 MMT CO_2e through 2030 and annual sequestration of almost 6 MMT CO2e starting in 2030. Avoided energy emissions due to reduced heat island effects would equal 728,000 MT CO2e/yr (Nowak et al 2017). This yields an annual CO2e benefit of over 6.7 MMT CO2e by 2030.

Recommendation: Immediately initiate urban greening across all CA urban landscapes as appropriate; fully engage urban greening opportunities across the state by 2030.

Urban Area	Urban Forest	Urban Tree Cover	Urban Tree Cover Goal	Urban Forest Seq. Rate	New Seq. through 2030	Total Seq. in 2030
Acres	*Acres*	*%*	*Acres; %*	*t C/ac/yr*	*MMT CO_2e*	*MMT CO_2e/yr*
6,754,956	736,290	10.9	1.473M; 21.8	4.04	32.72	5.95

Table 3. Estimated carbon storage and annual sequestration, including percent urban tree cover and amount of urban land (Nowak and Crane, 2002; FCAT, 2018, p. 110; Bjorkman, et al., 2015).

Estimated, Optimized Gross CO_2e Benefits:

- ***Cumulative by 2030: 289 MMT CO_2e***
- ***Annually, 2030 and beyond: 100 MMT CO_2e***

Recommendations and Conclusion

Policy and Program Recommendations

While the State of California to date has elected to fund individual practices on individual farms through the CDFA Healthy Soils and Alternative Manure Management Programs, a more comprehensive approach is required if the potential of the state's soils and working lands is to be realized. Carbon farming and other climate-smart agricultural strategies that engage a comprehensive, whole-farm planning process focused on maximizing the carbon capture potential of the working farm or ranch, and supported by technical assistance from Resource Conservation Districts (RCDs), USDA-NRCS programs, UC Cooperative Extension, and NGOs across the state, offer a holistic framework for optimizing carbon capture on the state's working lands.

In order to increase adoption of carbon farming practices at a scale consistent with the potentials outlined above, agricultural producers need:

1) support from a robust network of technical assistance providers
2) targeted and flexible funding for planning, implementation, and monitoring of carbon farming practices
3) a sufficiently trained and skilled workforce for on-the-ground implementation
4) an enabling regulatory environment
5) markets for climate-beneficial products coming from our working lands
6) an educated public that recognizes and values the central role working lands play in climate change mitigation and adaptation

All of these efforts must be designed to address the needs of vulnerable populations, especially farmworkers and disadvantaged communities. The full participation of these groups is key in the design, advocacy, and implementation of successful natural and working lands sequestration policies and programs. Recent research underscores the importance of their participation in this process – the San Joaquin Valley Region Report of California's Fourth Climate Change Assessment finds that poor farm communities will be impacted most severely by rising temperatures (Fernandez-Bou, et al., 2021). The following policy pillars[12] are needed to accelerate carbon sequestration on California's working lands:

Scale up state and local funding for carbon sequestration on working lands to meet the 2030 goal, assuming a total expenditure of at least $29 Billion (290 MMT CO2e @ $100/MT) through 2030

- State Funding Programs: Governor and state legislature allocate at least $10B over ten years to a portfolio (preferably consolidated) of state programs supporting carbon sequestration on working lands, including: Healthy Soils Initiative (CDFA, including AAMP); Climate Ready (State Coastal Conservancy); Climate Resiliency and Adaptation (WCB); Sustainable Agricultural Lands Conservation (DOC, third leg), and Urban Greening and Green Infrastructure (CNRA). The State should work actively to secure matching funds from the federal government through USDA and USEPA (Farm Bill and climate, Green New Deal, or American Jobs Plan legislation). At the same time, some program characteristics could be improved to increase accessibility. The Healthy Soils Program, for example, could benefit

[12] Some of these pillars were developed by a coalition of sustainable agriculture, climate and environmental organizations and are contained within "Carbon Neutral Agriculture In California By 2030: A Pathway To Economic, Ecological, And Social Resilience (Recommendations to Governor Newsom's Administration)," available here.

from streamlined applications and reporting, which are at present seen as onerous by some farmers and may exclude under-resourced farmers from applying. Increased technical assistance through Resource Conservation Districts (RCDs) will be needed to further enhance these programs' effectiveness (see below).

- Local Funding: Regional, county, and local governments commit a combined $5-10B over the ten years to support local partnerships on carbon sequestration on working lands, modelled after programs such as Santa Clara County's Agricultural Resilience Initiative. Local governments should work actively to secure matching funds from the state and federal government through climate-related federal infrastructure, jobs, and other legislate packages.
- Partner with the private sector: While this could fall outside the realm of state policy, it is worth noting as another potential mechanism to speed the growth of existing programs. Campaigns to work with and enroll private agriculture industry groups like the California Association of Winegrape Growers, California Sustainable Winegrowing Alliance, the California Almond Board, and the California Cattlemen's Association, for example, in the commitment to fund and implement soil health practices could increase the speed of overall adoption.

Implement holistic water policies and incentives programs that acknowledge working land soils as critical water storage and climate mitigation assets

- Given that climate change will aggravate uncertainty in future water supplies, decision-makers should include soil health enhancement as a strategy when considering water policies (e.g., as an approach to reducing agricultural water demand). Include carbon and soil health outcomes in water policies and programs as a strategy for GHG reduction, water conservation and management, water quality improvement, and agricultural water use efficiency.

Leverage the amplifying power of compost to accelerate soil carbon sequestration

- Over 74% of the climate benefit summarized in Table 1 derives from compost applications on the state's combined croplands, rangelands and pasture lands, and associated avoidance of synthetic nitrogen fertilizer production and use. These practices are consistent with state statutory requirements to divert millions of tons of organics from landfills, and the need to reduce short lived climate pollutants (SB1383 or the Short-Lived Climate Pollutant Reduction Strategy; ARB 2017) through beneficial reuse of millions of tons of livestock manures, orchard waste, and fire fuel reduction biomass over the coming years. Diversion of the state's multiple organic waste streams to compost production and beneficial soil application is the most obvious near-term opportunity to engage agricultural lands in climate change mitigation while simultaneously addressing pressing state water security and biodiversity issues. Supporting the capacity of farms and ranches to build agroecosystem carbon in situ, using the full suite of appropriate conservation practices, including on-farm composting, is the long-term best management approach to realizing the enormous potential of the state's working lands for carbon, water, biodiversity, crop production, and climate resilience benefits.
- Provide funds for incentive payments that support compost infrastructure statewide and compost use by producers to meet state CDR goals, producer soil fertility demands and the needs of SB 1383 implementation, including:
    - Removal of regulatory barriers to on-farm and municipal scale compost production

- Funding for on farm compost TA through RCDs and UCCE

Provide funding and technical assistance to land managers for planning, implementing, and monitoring whole farm approaches to carbon sequestration

- Permanent annual core funding for RCDs, UC Cooperative Extension, and Conservation Corps to scale-up planning and implementation (modeled on states like Washington, New York and North Carolina that support their conservation districts and other supporting public institutions)
- As a corollary to technical assistance, job training and workforce development programs must be enhanced to create at least a tenfold increase in skilled staff to scale-up regional carbon farming and climate-smart agricultural programs. Create at least one permanent full-time equivalent position to deliver carbon farming technical assistance in every RCD and UC extension office in the state.
- Prioritize access to land and technical assistance for carbon farming for Black, Indigenous, and People of Color (BIPOC) farmers and small and mid-scale, diversified family farmers throughout California, with focus on the Central Valley, Central Coast, Southern California, and tribal communities.

Significant investment in infrastructure to support on-farm carbon sequestration projects, including plant nurseries and equipment

- Create infrastructure grants that support equipment and materials needed for large-scale implementation of on-farm carbon farming projects, such as equipment for no-till operations, compost production, compost spreaders, greater availability of nursery stock for herbaceous and woody plantings across the state, and EV trucks and tractors, etc.
- Leverage funding through bonds (e.g., AB125 or the Equitable Economy Recovery, Healthy Food Access, Climate Resilient Farms, and Worker Protection Bond Act of 2022), state surplus budget funds, federal grants, the Climate Catalyst Fund at the Infrastructure and Economic Development Bank, or other sources to meet carbon sequestration targets.

Reduce synthetic N use in the state

- This can be achieved through recycling of organic nitrogen sources, preferably as compost, ultimately avoiding up to 11.7 MMT CO2e annually and significantly reducing the associated burden on the state’s ground and surface waters and air quality, including the potent GHG N2O (Rosenstock et al 2013, CNA 2015, Almaraz et al 2018).

Conclusion

Overall, the above analysis yields a potential to sequester nearly 290 MMT of CO2e on the state’s NWL by 2030 and 100 MMT CO2e annually after that, *without maximizing opportunities under any of the above scenarios and without engaging the numerous other on-farm carbon-sequestering conservation practices promoted by USDA-NRCS for the past 80 years.* As California confronts its inability to meet its climate targets through emission reductions alone, the NWL sector’s capacity to do “more than its share” will become increasingly important. The scenarios outlined above suggest how NWL generally (including some urban lands), and agriculture in particular, can be engaged to help the state meet its GHG reduction imperative through a comprehensive carbon dioxide removal strategy. The climate crisis demands nothing short of an economy-wide mobilization of resources to slow and reverse the emissions trends while also removing past climate pollution from the atmosphere. The strategies in this report represent a major component of creating a just and climate-safe future for all.

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