May 2015

Short-Lived Climate Pollutant Reduction Strategy

CONCEPT PAPER

California Environmental Protection Agency
Air Resources Board

This page is intentionally left blank.

Preface

California must achieve deep reductions in short-lived climate pollutant (SLCP) emissions by 2030 to meet future greenhouse gas emission targets and air quality goals. In addition, intensified, global action to reduce these emissions is the only way to immediately slow global warming and is necessary to keep warming below 2^{o}C through at least 2050, which is a critical threshold to manage the damaging effects of climate change. Short-lived climate pollutants, which include methane, fluorinated gases (F-gases), black carbon, and tropospheric ozone, are among the most harmful to both human health and global climate.

Significant reductions in SLCP emissions can be achieved globally using cost-effective technologies and strategies, some of which have already been demonstrated effectively in California. Over the past several decades, the State's efforts in controlling harmful emissions have prevented thousands of premature deaths in California, saved the State many tens of billions of dollars in energy and health costs, and have occurred alongside strong economic growth throughout our diverse economy. Applying California's experiences to reduce SLCPs globally would help prevent millions of premature deaths; boost agricultural productivity; limit disruption of historic rainfall patterns; slow the melting of glaciers, snowpack, and sea ice; reduce sea level rise; and provide trillions of dollars in economic benefit each year.

California has taken significant steps in reducing SLCP emissions, especially black carbon from transportation, methane from oil and gas operations and landfill emissions, and F-gas emissions from refrigerants, insulating foams, and aerosol propellants. Still, more remains to be done to reduce emissions from these and other sources in the State, including methane from waste management and dairies, black carbon from fossil-fuel combustion and biomass burning, and F-gas emissions from refrigeration and air conditioning systems. The State is committed to further reducing SLCP emissions.

The Legislature recognized the critical role that SLCPs must play in the State's climate efforts with the passage of Senate Bill 605 (Lara, Chapter 523, Statutes of 2014), which requires the Air Resources Board (ARB) to develop a strategy by the end of 2015 to further reduce SLCP emissions. In his 2015 Inaugural Address, Governor Brown reinforced this commitment and called on California to show the world the path to limiting global warming below 2^{o}C through 2050, while highlighting the role that action to cut SLCPs must play in this effort. In April, the Governor set a target for reducing greenhouse gas emissions to 40 percent below 1990 levels by 2030, which the actions identified in the Strategy will support.

This Concept Paper presents initial ideas that will be considered and evaluated in the coming months by ARB, in coordination with other agencies, as it develops a SLCP Strategy pursuant to SB 605. The Concept Paper will be discussed at a May 27, 2015, public workshop. Comments received on the Concept Paper will inform the development of a draft Strategy that ARB expects to release later this summer for public review. ARB welcomes broad participation among stakeholders, experts and interested

parties throughout this process, which will be important to the development of an effective Strategy. The workshop notice, along with any other additional material related to the development of the Strategy, will be posted on ARB's SLCP website at: http://www.arb.ca.gov/cc/shortlived/shortlived.htm.

Table of Contents

Significant Benefits from Accelerated Action on Short-Lived Climate Pollution

Short-lived climate pollutants (SLCPs) include methane (CH_4), tropospheric ozone (O_3), black carbon (soot), and fluorinated gases (F-gases, including hydrofluorocarbons, or HFCs). They are powerful climate forcers that remain in the atmosphere for a much shorter period of time than longer-lived climate pollutants, including carbon dioxide (CO_2), which is the primary pollutant regulated under AB 32. Their relative potency, when measured in terms of how they heat the atmosphere, can be tens, hundreds, or even thousands of times greater than that of CO_2. SLCPs may be responsible for about 40 percent or more of global warming experienced to date.[1,2,3,4]

Cutting emissions of these pollutants is the *only* way to immediately slow global warming and reduce the impacts of climate change. While CO_2 is the most abundant well-mixed greenhouse gas (GHG) and primarily responsible for global warming, it has an average lifetime of 100 years or more, and CO_2 emissions today will continue to warm the planet for decades to come. On the other hand, about 90 percent of the decrease in the global mean temperature that would accrue from cutting emissions of SLCPs would occur within about a decade.[5] Ultimately, immediate and significant cuts in emissions of both short-lived and long-lived climate pollutants, especially CO_2, are needed to keep average warming below 2^{o}C this century.

Cutting emissions of SLCPs can also often be accomplished quickly and effectively, by putting emission control devices on existing equipment and infrastructure. Therefore, it is within our grasp to significantly cut emissions of SLCPs from worldwide sources by 2030.

While some sources will remain difficult to control over the next 15 years – especially natural sources – existing strategies can cost-effectively reduce global methane emissions an estimated 40 percent and black carbon an estimated 80 percent below reference levels in 2030.[6] Additionally, a new global phase-down of HFCs under the Montreal Protocol and other efforts could cut the expected use of F-gases by more than 50 percent in 2030.[7,8]

Achieving these levels of global reductions would deliver significant climate benefits. It would cut the expected rate of global warming in half by 2050, or by about 0.6^{o}C,[9,10] which is about four times more than the reductions in warming that may come by 2050 from action on CO_2 alone.[11] It would also increase the probability of staying below the 2^{o}C threshold to more than 90 percent through 2050.[12,13]

The benefits could be even greater in the Arctic, which is especially vulnerable to black carbon emissions and is warming twice as fast as the rest of the world.[14] The current rate of warming there could be slowed by two-thirds by 2040, or 0.7^{o}C, due to these levels of emission reductions.[15] This could be critically important for stabilizing climate change and its impacts, as the Arctic is an important driver of sea level rise and weather patterns throughout the Northern Hemisphere, with changes there potentially affecting drought in California and extreme snow and cold in the upper Midwest and New England, although such links have not been definitively proven.[16,17] Accelerated

warming in the Arctic could also lead to irreversible climate "tipping points," such as release of vast quantities of CO_2 and methane from melting permafrost.[18]

Global mean sea level will continue to rise during the twenty-first century, and the rate of sea level rise will exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets. Sea level rise is an important impact of climate change on California due to the long coastline and large population that lives near coastal waters. A recent study shows that SLCP mitigation can have significant benefits for limiting sea level rise. It can slow down the rate of sea level rise by roughly 25-50 percent this century.[19]

Black carbon is a component of fine particulate matter (PM2.5) resulting from combustion sources such as biomass burning and diesel emissions; diesel emissions are also carcinogenic. Recent studies suggest that deploying existing, cost-effective technologies to reduce SLCP emissions can also cut global emissions of PM2.5 by 50 percent, oxides of nitrogen (NO_x) emissions by 35 percent, and carbon monoxide (CO) emissions by 60 percent.[20] If these measures were fully in place by 2030, an estimated 2.4 million premature deaths and 53 million metric tons of crop losses could be avoided globally, per year. The economic value of these climate, crop, and health benefits is estimated to be about $5.9 trillion annually.[21]

In addition to its climate and health impacts, black carbon (as a component of PM) disrupts cloud formation, precipitation patterns, water storage in snowpack and glaciers, and agricultural productivity.[22] In California, State and international action to reduce emissions of SLCPs can improve air quality and reduce related health risks, hospitalizations and medical expenses, especially in disadvantaged communities. Other benefits to California include reducing damage to forests and crops, reducing background ozone and particulate levels to help meet federal air quality standards, and reducing disruption of historic rainfall patterns. California is working with a set of national and subnational partners throughout the world to fight air pollution and climate change, which will help deliver these benefits to our State while providing significant benefits where emission reductions occur.

Strengthening California Climate Leadership

Prompt global action to reduce emissions of SLCPs offers tremendous global climate, economic, food security, and health benefits, and will help us achieve our international goal of stabilizing global warming at or below 2°C this century. Modeling results suggest that delaying global efforts to cut methane emissions until 2030 or black carbon emissions until 2040 would lead to crossing the 2°C threshold by 2050.[23,24]

California is already a leader on reducing emissions of SLCPs:

- *Black carbon:* California has cut anthropogenic sources of black carbon emissions by more than 90 percent since the 1960s, and will cut them in half again by 2020. These efforts prevent an estimated 5,000 premature deaths in the State each year, and deliver important climate benefits. If the world

replicated this success, it would slow global warming by an estimated 15 percent,[25] essentially offsetting one to two decades' worth of CO_2 emissions.[26]

- *Methane:* California has the nation's strongest standards for limiting methane emissions from landfills, has existing or proposed offset protocols under our Cap-and-Trade program to reduce methane emissions from dairies, coal mines, and rice cultivation, and has rules under development and being implemented that should create a comprehensive approach to limit methane leaks from the oil and gas sectors.
- *F-gases:* California is the only subnational jurisdiction in the world with an inventory for F-gas emissions, a Cap-and-Trade offset protocol incentivizing the capture and destruction of ozone depleting substances (which are also F-gases), and regulations in place that will cut emissions of F-gases by 25 percent below projected levels in 2020.

Still, more remains to be done. California is home to some of the highest levels of air pollution in the country, and although the State has substantially reduced particulate matter and black carbon emissions from on-road transportation, vehicles still pollute the air in our communities and harm the lungs of some of our most vulnerable populations. Methane is responsible for about 25 percent of current global warming, and its emissions continue to increase in California and globally. F-gases, specifically HFCs, are the fastest growing source of GHG emissions in California and globally. California is committed to expanding upon its leading climate and air quality policies with a targeted effort to significantly cut emissions of SLCPs.

The Legislature and Governor Brown further solidified the State's commitment to addressing short-lived climate pollution by passing and signing Senate Bill 605 (Lara, Chapter 523, Statutes of 2014). Accordingly, ARB will develop a plan in 2015, in coordination with other state and local agencies, to integrate planning, ongoing efforts, and identify new measures to help overcome obstacles and significantly cut SLCP emissions through 2030.

Many of the benefits of cutting SLCP emissions in California will accrue in the most disadvantaged parts of the State, where pollution levels and their health impacts are often highest, and where further economic development may be most needed. For example:

- Further cutting black carbon emissions from the transportation sector and building a sustainable freight system would have health and economic benefits for communities in Southern California and the Inland Empire along freight corridors and near ports and railyards where diesel particulate matter concentrations are high;
- Investments to cut methane and black carbon emissions as part of an integrated strategy to reduce emissions from agriculture and waste and support healthy soils and a resilient and competitive agricultural sector, can support jobs and economic growth, and improved public health throughout the Central Valley;

- Improving management and health of forests and rural landscapes to mitigate black carbon emissions from wildfires and biomass burning can help bring investment, economic, and climate resiliency benefits throughout the Sierra and other rural parts of California; and
- Switching to low-global warming potential (GWP) refrigerants in air conditioning systems can also improve their energy efficiency, which can help to cut transportation fuel consumption and electricity bills throughout the State, especially in the hottest climate zones, including the Central Valley and San Bernardino, Imperial, Inyo, and Riverside counties.

By highlighting the critical role that SLCPs play in addressing climate change, the significant benefits associated with strong action to reduce them, and committing to strong action to reduce emissions of both SLCPs and CO_2 in 2020, 2030, and beyond, California can strengthen its climate leadership and accelerate global progress to limit global warming and the impacts of climate change.

Foster International Action to Significantly Reduce SLCP Emissions and Impacts

California is already fostering broad action to reduce SLCP emissions. California is actively engaged with national and subnational governments in China, India, Mexico, U.S. states, Canadian provinces, and elsewhere in efforts to reduce GHG emissions and air pollution. Many of these efforts will help reduce emissions of black carbon from the transportation sector and emissions of other SLCPs, including activities with Mexico pursuant to a Memorandum of Understanding signed in 2014. Additionally, last September at the United Nations (UN) Climate Summit, ARB became the first state-level entity to sign onto action statements of the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants. At the UN climate negotiations in Lima, California co-sponsored an event with Mexico on SLCPs and their role in an international framework to contribute to national commitments to reduce emissions. We continue to be committed to acting both bilaterally and multilaterally to cooperate with other jurisdictions to cut SLCP emissions.

Building on leadership around SLCPs can provide an important example for action in other countries and jurisdictions, and is one of the most significant opportunities to accelerate international progress to fight climate change. California is in a unique position to serve as a model for action for other countries and jurisdictions to accelerate their progress to reduce emissions of both SLCPs and CO_2, based on our demonstrated leadership on air quality and climate change, commitments to set stringent, science-based targets to reduce emissions of both CO_2 and SLCPs, and integrated planning efforts like this one to develop comprehensive policy frameworks to achieve those goals. As we have done for decades already, California's actions on SLCPs can demonstrate win-win opportunities for both the most developed countries, where reducing SLCP emissions is an important element of broad efforts to cut GHG emissions, as well as for the least developed countries, where SLCP reductions have tremendous benefits for air quality and human health.

"At national and sub-national scales many of the identified [SLCP] measures could be implemented under existing policies designed to address air quality and development concerns. Improved cooperation within and between regions would enhance widespread implementation and address transboundary climate and air quality issues." – UNEP (2011) *Integrated Assessment of Black Carbon and Tropospheric Ozone*

In developing the Strategy, California will look to build on its international leadership position on climate change and air quality. The Strategy will identify and prioritize opportunities to expand action on SLCPs beyond our borders, and look to learn from others who are implementing programs new to us, including landfill diversion and anaerobic digestion. The State will also explore additional opportunities to further reduce air pollution, greenhouse gas, and SLCP emissions through its existing partnerships, perhaps including collaborative pilot programs or other efforts to collectively reduce emissions.

Ultimately, each state, region, or country has its own mix of SLCP sources, needs, and opportunities to reduce emissions. While we are developing a Strategy to address our own, we will also look to highlight the critical role that this type of planning and goal setting plays in helping to successfully reduce emissions and maximize local and global benefits. We will share this planning effort with others, and encourage them to adopt specific SLCP reduction targets and plans to achieve them. A few already have – President Obama has set specific targets to cut methane emissions from the oil and gas sector, Mexico has included targets to cut black carbon emissions in its Intended Nationally Determined Contribution to the United Nations Framework Convention on Climate Change, and Norway has developed an SLCP action plan of its own.[27] But these types of commitments and planning efforts need to be adopted much more broadly, and by developing a comprehensive plan to achieve necessary SLCP reductions in an effective and beneficial way, California will continue to foster broader action beyond its borders, and demonstrate effective processes and strategies to address climate change.

Process for Developing a Short-Lived Climate Pollutant Strategy

The 2014 Scoping Plan Update identified SLCPs as an important aspect of a comprehensive approach to addressing climate change. It committed ARB to develop a short-lived climate pollutant strategy in 2015 as part of a broad effort to reduce emissions of all GHGs from all sources – including CO_2 from energy-related activities, as well as emissions from natural and working lands, and N_2O.

Senate Bill 605 reaffirmed and codified that commitment. The bill requires ARB to "develop a comprehensive strategy to reduce emissions of SLCPs in the state" by January 1, 2016, and in developing the strategy to:

- Complete an inventory of sources and emissions of SLCPs in the State based on available data;
- Identify research needs to address any data gaps;

- Identify existing and potential new control measures to reduce emissions;
- Prioritize the development of new measures for SLCPs that offer co-benefits by improving water quality or reducing other air pollutants that impact community health and benefit disadvantaged communities, as identified pursuant to Section 39711;
- Coordinate with other state agencies and districts to develop and implement measures identified as part of the comprehensive strategy;
- Consult with experts in academia, industry, and the community on SLCPs. The topics shall include, but not be limited to, all of the following:
    - Assessment of the current status of controls that directly or indirectly reduce emissions of SLCPs in the State.
    - Identification of opportunities and challenges for controlling emissions.
    - Recommendations to further reduce emissions.
- Hold at least one public workshop during the development of the strategy.

Pursuant to these requirements, ARB will develop a Short-Lived Climate Pollutant Strategy (Strategy), in coordination with other state agencies and local air districts, which will be presented to the Board in the fall of 2015. An estimated timeline for development of the Strategy and public engagement is provided in Table 1. Public engagement will include public workshops and Board meetings, as well as input and review by climate science, industry experts, and other interested stakeholders.

Table 1: Estimated Timeline and Process for Developing a Short-Lived Climate Pollutant Strategy.

May	Release SLCP Concept Paper / Public workshop
Summer	Release initial draft of Strategy / Public workshop
Fall	Release draft proposed Strategy
Fall	Present draft proposed Strategy to Board
Spring 2016	Present final Strategy to Board for approval

This Concept Paper describes initial ideas that will be explored over the next several months as the Strategy is developed. The concepts included in this discussion draft do not represent commitments at this time, nor do they comprise an exhaustive list of elements or considerations that may be included in the Strategy or shape its development.

Indeed, the intention of this paper – and the public process that follows – is to elicit new ideas and refine strategies to reduce emissions of SLCPs throughout the State. ARB welcomes broad participation among stakeholders, experts, and interested parties throughout this process.

Strategy Scope

The Strategy will explore opportunities to reduce emissions from all major sources of methane, black carbon, and F-gases. Regarding F-gases, the Strategy will primarily focus on reducing emission of HFCs, but may explore opportunities and research needs to reduce emissions of some other F-gases. Tropospheric ozone will not be considered independently, as it is not directly emitted.

The Strategy will aim to identify and develop systems-level solutions that move beyond individual projects and enable deep, sector-wide emission reductions. For example, developing a comprehensive approach for utilizing organic waste from a number of sources for energy, soil amendment, or other purposes will require coordinating a broad array of tools – including regulatory measures, incentives, and public investment – that work across sectors to address various economic, institutional, or technological issues.

For some sectors, further research efforts are critical to understanding costs and benefits associated with reducing SLCP emissions. The Strategy will identify ongoing research and additional research needs to further advance the science regarding inventory methods and reduction measures, determine expected reductions from mitigation strategies, and account for the climate impacts of SLCPs in California.

In accounting for the climate impacts of SLCP emissions, ARB will evaluate inventories based on 20-year and 100-year GWP values (see Table 2). Global warming potentials account for the lifetime of different greenhouse gases in the atmosphere, and the amount of energy they absorb on a per-kilogram basis, relative to CO_2, to represent the relative climate forcing of a kilogram of emissions when averaged over a time period of interest (for example, 20 years or 100 years). Current practice in most of the world for developing GHG emission inventories, including California's inventory, is to use 100-year GWP values from the 4th Assessment Report of the Intergovernmental Panel on Climate Change, which was released in 2007. The 4th Assessment did not include GWP values for black carbon, however, so values from the 2013 5th Assessment Report are used here.

The latest scientific consensus, as reflected by GWPs included in the 5th Assessment Report, suggests that methane emissions have an even greater impact on climate change than previously understood. While developing the Strategy, including in consultations with experts and stakeholders, ARB will consider the best methods to account for the costs and benefits associated with proposed measures to reduce emissions of SLCPs.

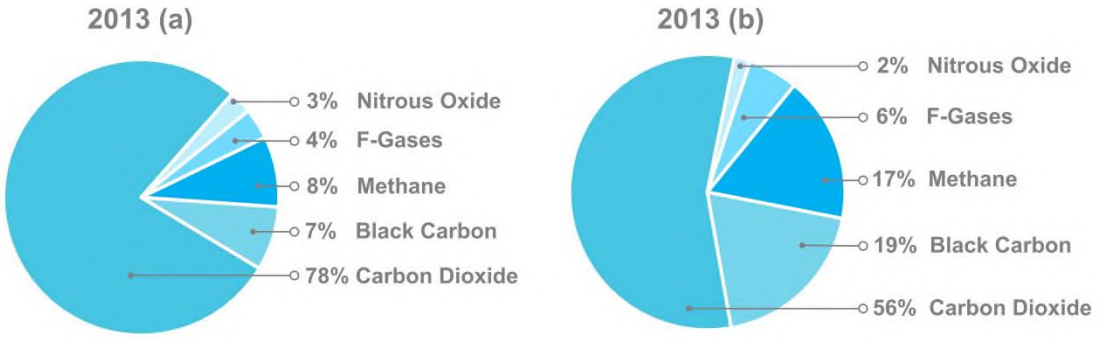
Table 2: Global Warming Potential for SLCPs to be used in the Strategy

Pollutant	Lifetime (years)	GWP time horizon	
		20 years	100 years
Carbon dioxide	100	1	1
Methane	12	72	25
F-Gases (Hydrofluorocarbons)*	1.4 – 52	437 – 6350	124 – 4470
Black carbon	Days to weeks	3,200	900

* Does not include two long-lived HFCs with negligible emissions.

Figure 1 presents California's greenhouse gas inventory, using 100-year and 20-year GWPs. The impact of SLCPs on global warming more than doubles, to just over 40 percent of California's inventory, when GWPs are computed over 20 years, rather than 100 years.

Figure 1: California's 2013 Greenhouse Gas Inventory Using (a) 100-year and (b) 20-Year Global Warming Potential Values



In addition to minimizing climate risks, immediate action to reduce emissions of SLCPs can deliver a broad array of benefits throughout California. A wide range of benefits will be accounted for when considering potential measures related to short-lived climate pollution, and as called for in Senate Bill 605, the Strategy will identify and prioritize measures that complement and accelerate progress to meet other economic, health, social equity, and environmental objectives.

The Strategy fits within a wide range of ongoing planning efforts throughout the State to advance economic and environmental priorities. Integrated planning to achieve multiple objectives requires coordination among planning agencies and across sectors, systems, and government jurisdictions. Development of the Strategy will be closely coordinated with other relevant planning efforts. For example, new SLCP emission reduction concepts for California's freight system will align with strategies identified in the Sustainable Freight Strategy. That plan is currently being developed by ARB and other state agencies, and will identify strategies that will further reduce black carbon emissions throughout the freight sector. Other concurrent planning efforts in the State

could also identify additional activities that may serve to reduce SLCP emissions. For example, CEC's Integrated Energy Policy Report, the State Implementation Plan, the Healthy Soils Initiative, and the Forest Carbon Plan are all ongoing efforts that intersect with many of the concepts described in this paper. ARB will collaborate with other agencies developing those plans to identify and prioritize activities to reduce SLCP emissions that would also support other State priorities and integrated planning efforts. Climate action planning efforts by city, county, and other local government entities will also play a role in reducing SLCP emissions.

State Plans that Will Assist the State in Meeting the SLCP Emission Reduction Goals	
✓ Sustainable Freight Strategy ✓ 2014 Scoping Plan Update ✓ Additional Scoping Plan Updates ✓ Three Year Auction Proceeds Investment Plan ✓ Funding Plan for the Air Quality Improvement Program (AQIP) and Low Carbon Transportation Greenhouse Gas Reduction Fund Investments	✓ 2016 State Implementation Plan ✓ ARB's Annual Research Plan ✓ CAT Climate Change Research Plan for California ✓ Water Action Plan ✓ DWR's Climate Action Plan ✓ Caltrans Strategic Management Plan for 2015-2020 ✓ Forest Carbon Plan ✓ Healthy Soils Initiative

Framing the Strategy

A number of overarching concepts will frame the development of the Strategy, which are described below.

Achieve Scientific-Based Targets

The Strategy will identify and recommend measures to achieve SLCP emission reductions that scientific studies suggest are necessary – globally, and in conjunction with immediate and significant reductions in CO_2 emissions – to limit global warming to less than 2^oC, as well as to support Governor Brown's new climate goal of reducing California's GHG emissions to 40 percent below 1990 levels by 2030. [*] Specifically, the Strategy will:

- Describe ongoing and developing efforts (e.g., Sustainable Freight Strategy, Diesel Risk Reduction Plan, State Implementation Plan, Forest Carbon Plan) that have achieved significant black carbon reductions already or seek to reduce black carbon emissions further; these efforts and others that will be identified, are

[*] Executive Order B-30-15

expected to reduce black carbon emissions by at least 50 percent below 2012 levels from transportation sources by 2020, and from all sources by 2030;
- Identify existing and potential new measures to reduce methane emissions by at least 20 percent by 2020 and 40 percent by 2030, below forecasted emission levels; and
- Identify existing and potential new measures to reduce F-gas emissions by at least 25 percent in 2020 and 50 percent in 2030, below forecasted emission levels.

Prioritize Actions with Diverse Benefits

The direct benefits of cutting SLCP emissions will be immediately tangible, and can be substantial. As part of an integrated strategy to not only reduce emissions of SLCPs, but also to develop renewable sources of energy and strengthen the competitiveness and resiliency of our agricultural, forestry, freight and other sectors, they can deliver even greater benefits, including:

- Reduced asthma risk, hospitalization, premature death, and associated medical costs from air pollution;
- Reduced global and localized climate change impacts, including sea level rise and disrupted precipitation patterns, and associated costs;
- Reduced crop losses from air pollution;
- Healthier forests, wildlife habitats, and watersheds;
- Healthier soils that are more sustainable and resilient to climate change, sequester GHGs, require less synthetic amendments, and improve water retention;
- Increased availability of renewable fuels and energy, to stabilize energy costs and reduce emissions from buildings, industry, power plants, and transportation; and
- Stronger agricultural and freight sectors that are well positioned to continue competing globally and growing as a source of jobs and economic development in California.

Clearly, there are a number of drivers and benefits to reducing SLCP emissions that extend beyond mitigating the impacts of climate change. The Strategy will frame these broad benefits and identify priority measures to provide a wide array of climate, health, and economic benefits throughout the State.

Put Organic Waste to Its Most Beneficial Use

In most cases, organic material can be a potential resource, not a waste stream. By treating and utilizing organic waste streams in better ways, we can significantly cut methane emissions from existing or new landfill, dairy, wastewater treatment, or other waste management operations, as well as black carbon emissions from agricultural burning or prescribed burns and wildfires. We can also create new sources of jobs and economic activity, renewable power or natural gas, clean transportation fuels, and

expand the production and use of compost and other beneficial soil amendments in the State. Many renewable fuels from organic waste streams have the lowest carbon intensity in the Low Carbon Fuel Standard, which provides an economic incentive for utilizing those resources for expanded fuel production. Soil amendments may improve soil health and water retention and reduce the use of synthetic amendments in agriculture. Indeed, strategies to improve management and utilization of organic waste throughout the State may have the ability to help reduce emissions throughout the agricultural sector, from avoided methane emissions from manure, CO_2 emissions from fuel use, and N_2O emissions (a very potent, but *long-lived*, GHG) from fertilizer use and soils.

Wherever possible, and as soon as possible, we should be utilizing organic waste in order to both reduce SLCP emissions and produce maximum value from the energy and nutrients that remain in these sources. Toward those ends, in developing the Strategy, the State will work with researchers and stakeholders to identify the cost, feasibility, and potential funding mechanisms, incentives, regulations and other strategies – on the supply and demand side – to maximize the beneficial use of organic waste.

Identify Practical Solutions to Overcome Barriers

Achieving the SLCP emission reduction targets identified above will require overcoming stubborn barriers, and in some cases, modifying operations and updating best practices, to significantly reduce SLCP emissions from sources that may have been difficult to control in the past. For example, cheap and abundant landfill capacity makes organics diversion and utilization difficult. Developing projects that not only generate renewable energy, but also improve air quality and protect water quality may require additional investments in the cleanest technology and management practices, while navigating through various permitting processes. Collection and utilization of dispersed woody biomass resources, such as agricultural wastes or forest thinnings, may suffer from poor economies of scale, which limit the feasibility of extracting energy from these resources. Utility engagement and interconnection – getting electricity onto the grid or renewable gas into the pipeline – remains an unnecessarily long and costly process in many parts of the State. Technology or market barriers also remain in some sectors, such as developing cleaner engine and fuel options for off-road equipment and other vehicles and operations throughout the goods movement supply chain. In other sectors, such as those using refrigerants, cleaner, low-GWP options are just beginning to emerge, and markets for these options need to be supported and scaled.

These barriers are not insurmountable. Through coordinated planning to align priorities and streamline permitting, targeted investment and incentives to overcome cost barriers to clean technologies and practices, and direct engagement with farmers and ranchers, landfill operators, waste haulers, and other stakeholders, we can overcome these barriers and significantly cut SLCP emissions and improve the health and vibrancy of communities throughout California.

For example, the Strategy will identify strategies and funding mechanisms to encourage and streamline the use of the cleanest technologies to advance the State's air quality,

water quality, climate change, and other environmental objectives. Such technologies or strategies may include fuel conditioning of biogas to remove contaminants before vehicle use, injection into the natural gas pipeline, or fuel cells for electric generation. Several existing programs already provide potentially significant incentives to convert waste streams to various forms of energy, but others will be considered to further encourage the use of energy from organic waste, including potential mechanisms that could increase the share of renewable natural gas used in California buildings, industry, and transportation.

Efforts to increase composting and anaerobic digestion should be accompanied by efforts to promote and account for the benefits of utilizing compost, manure, and other soil amendments that come from these processes. Increasing demand for compost and other soil amendments may be key to financing projects to utilize organic waste and cut emissions of SLCPs. ARB will coordinate with the California Department of Food and Agriculture (CDFA) and other agencies working on the Healthy Soils Initiative to identify additional research needs to inform the science and accounting methods necessary to quantify the various benefits of using compost and other soil amendments and address any potential problems such as buildup of salts or heavy metals in soil. Collaboration among state agencies, water districts, and local governments will help improve quantification of benefits and impacts that could enable greater use of compost in urban storm water management, remediation of fire-degraded lands, water conservation measures, and other beneficial uses. Agencies will also consider potential mechanisms to encourage the use of compost and other soil amendments in agriculture and various other applications in California, in ways that protect air quality, water supplies, and provide other benefits.

Finally, the State already has a number of research projects and multi-agency working group efforts underway to overcome barriers to accelerating deployment of compost and anaerobic digestion facilities, scrape systems and digesters at dairies, renewable natural gas generation at wastewater treatment facilities, and other technologies and strategies to reduce SLCP emissions. The Strategy will pull from all of these efforts and suggest measures to overcome barriers that may exist throughout the supply chain – including feedstock, technology, market/economics, permitting, technical feasibility, infrastructure/logistics, and user behavior.

Advance the Science of SLCP Sources and Emissions

Data related to SLCPs and their sources is often less available or of lower quality than it is for CO_2. One reason is that energy-related emissions of CO_2 are often easier to quantify than emissions of other GHGs, which may form through complex biological or other processes where existing reporting guidelines and procedures may not apply. But there has also been less of a focus on collecting additional data that could help to quantify GHG emissions from some non-CO_2 sources. While improving data access and quality is not prerequisite for many actions to reduce emissions of SLCPs, it is important for informing ongoing efforts to reduce emissions to necessary levels from these sources.

In addition to identifying current research efforts underway to advance the understanding of sources and emissions of SLCPs in California, the Strategy will explore potential reporting methods and requirements that could improve understanding of SLCP emissions and impacts in California. This may include activities to improve understanding of methane emissions from natural gas and oil supplied to California, dairy operations, landfills, as well as various sources of F-gas and black carbon emissions. Additionally, research needs to further understanding around the climate forcing impact of light-absorbing particles known as "brown carbon" (which mostly come from biomass burning), its sources in California, and potential mitigation options will be explored.

Invest in SLCP Emission Reductions

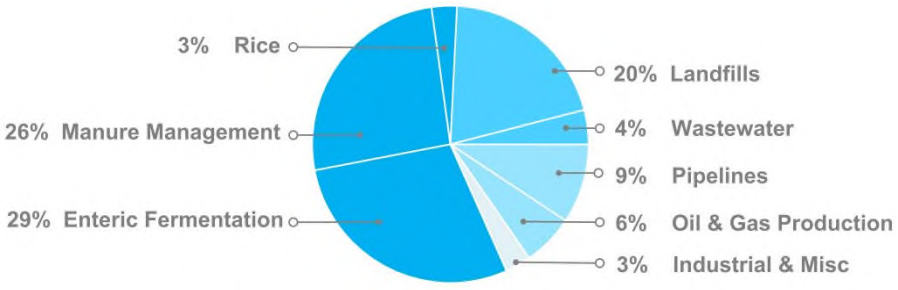
Achieving significant reductions in SLCPs will require substantial investments to provide incentives and direct funding for priority sectors, sources, and technologies. Significant investments of private capital, supported by targeted, priority investments of public funding, are necessary to scale deployment of technologies and strategies to significantly cut emissions of SLCPs throughout California and to maximize the benefits of doing so. Public investments should be smart and strategic, to leverage private investment and accelerate market transitions to cleaner technologies that foster significant, system-wide solutions to cut emissions of SLCPs, maximize resource recovery from organic waste streams, and provide economic and health benefits in agricultural, disadvantaged, and rural parts of the State. Examples may include targeted support to reduce emissions of SLCPs and CO_2 through integrated strategies at dairies, landfills and in organic waste management; throughout the freight system; in commercial refrigeration applications; and from the management of woody waste materials in the agricultural and forestry sectors.

The State will need to continue coordinating and utilizing funding sources such as the Greenhouse Gas Reduction Fund (Cap-and-Trade auction proceeds),[28] the Alternative and Renewable Fuel and Vehicle Technology Program (AB 118), Electric Program Investment Charge (EPIC) Program, Carl Moyer program, Air Quality Improvement Program, and the Proposition 39: Clean Energy Job Creation Fund to expand investments in California's clean economy and further reductions in SLCPs and other GHG emissions. Strategies identified during the development of the SLCP Strategy will help inform the recommendations in the Cap and Trade Auction Proceeds three-year Investment Plan that is currently being updated.

Potential new funding mechanisms and incentive structures will also be considered during the course of developing the Strategy. These could include adjusting the tipping fee structure to account for the true cost of managing organic materials and landfills, state procurement contracts for renewable natural gas and other fuels in buildings or vehicles, or labeling programs to recognize leading companies in the market place, including those producing milk with low levels of dairy methane emissions.

Methane Emission Reduction Concepts

Methane is the second largest, and a growing, component of GHG emissions in California (see Figure 2 for California's methane emission sources). The State has taken important steps to reduce methane emissions from all of its major sources, but more needs to be done to more fully control methane emissions, especially from organic waste streams going to landfills and at dairies.



Methane is the principal component of natural gas and is also produced biologically under anaerobic conditions in ruminant animals, landfills and waste handling. Since methane emissions come from many sources, including complex biological processes, it can be difficult to measure emissions from major sources. Coordinated research efforts between ARB and the California Energy Commission to refine emission estimates have led to the development of the only subnational methane monitoring network in the world. In addition, researchers at ARB and at NASA's Jet Propulsion Laboratory are currently collaborating to identify large "hot spot" methane sources in the San Joaquin Valley. This research will aid in future control and regulatory plans to reduce GHG emissions in California. The Strategy will catalog ongoing research efforts related to methane emission detection and highlight remaining research gaps.

Methane also contributes to global background levels of ozone in the lower atmosphere (troposphere). Ozone itself is a powerful SLCP as well as a regional ground level air pollutant. Ozone negatively impacts human health, and can lead to asthma attacks, hospitalizations, and even premature death. It impairs the ability of plants to absorb CO_2, thereby suppressing crop yields and harming ecosystems. Ozone also affects evaporation rates, cloud formation, and precipitation levels. In addition to the direct climate benefits of cutting methane emissions, it can also reduce global background levels of ozone pollution and provide additional climate, health, and other benefits. [29,30,31]

Regional ozone concentrations reflect contributions from ozone formed from emissions (oxides of nitrogen (NO_X), and volatile organic compounds (VOCs)) on a regional scale, as well as ozone transported on hemispheric scales (global background levels of ozone). Due to its low reactivity, methane emissions do not affect regional scale ozone production that occurs over hours to days. However, regional methane emissions which are fairly well-mixed in the atmosphere contribute to the global abundance of methane,

which in turn contributes to global background levels of ozone. About two-thirds of the rise in global levels of tropospheric background ozone can be attributed to methane emissions. Studies have also shown that the global background ozone concentrations can approach 40 ppb and have been increasing in recent years. Increases in background ozone raise the baseline upon which local-to-regional ozone builds.

Over the past 50 years, ARB and local air districts have implemented a comprehensive regulatory control strategy to continually reduce regional ozone formation in order to comply with health-based ambient air quality standards set under the federal Clean Air Act. Many rules and amendments have been adopted, which have more than cut in half the emissions of VOCs and NO_X, and significantly reduced ozone concentrations throughout California. Because the regulatory definition of VOCs does not include methane due to its relatively low reactivity and lack of impact on regional ozone production, methane emissions have not fallen at similar rates as VOCs over the past decades.

In California, agriculture and landfills are the primary sources of methane emissions. Including manure from agricultural operations, organic waste is responsible for more than half of the State's methane emissions. The Strategy will explore potential methane emission reductions from all sources, but will specifically look to significantly reduce emissions from the waste and agricultural sectors in the State, through integrated strategies that fully utilize organic waste streams to recover their maximum value.

Minimize Fugitive Methane Emissions from all Infrastructure and Equipment

Natural gas is currently California's largest source of electricity generation, energy for industrial operations, and GHG emissions from residential and commercial buildings. Its use in the transportation sector is also increasing, and it could potentially play an important role in helping many parts of the State comply with federal air quality standards over the next 20 years, especially if "ultra-low NO_x" natural gas engines become commercially available for heavy-duty trucks within the next few years.

As California continues to rely on natural gas for a large fraction of its energy supply, it is critical to increase supplies of renewable natural gas and minimize fugitive emissions of methane from natural gas infrastructure. Renewable natural gas can be captured at landfills, wastewater treatment plants, commercial food waste facilities, agricultural operations, or other sources, treated, and used as a renewable energy source to displace fossil fuel consumption. Due to its high global warming potential, relatively small levels of methane emissions throughout the supply chain can overwhelm any reduction in CO_2 emissions from the use of fossil or renewable natural gas, compared to oil or coal. In California, which uses little coal, the important comparison is to diesel fuel used in transportation. As we increase the number of facilities producing and using renewable supplies of natural gas, hydrogen, or any other potential source of methane emissions in a cleaner energy economy, we must also take steps to minimize potential methane leaks from those facilities.

Based on existing models and accounting frameworks, the use of conventional natural gas in the transportation and other sectors is reducing emissions in California, compared to the use of oil or coal. California also has ongoing efforts to further reduce fugitive methane emissions from oil and gas production. ARB is developing a regulation to reduce methane emissions from oil and gas production, processing, and storage operations, and the California Public Utilities Commission is developing rules, per SB 1371 (Leno, Chapter 525, Statutes of 2014), to reduce emissions from gas transmission and distribution pipeline leaks throughout the State. Together, these rules should create a comprehensive approach to limit methane leaks from oil and gas operations. However, about 90 percent of our natural gas comes from out-of-state suppliers, so the State will continue to advocate for strong national methane standards to ensure potential climate benefits from our use of gas in the State.

In developing the Strategy, ARB and other state agencies will consider additional data, measurement, and reporting needs and tools in order to improve the characterization of fugitive methane emissions from natural gas supplies to California. The Strategy will also consider potential measures to ensure climate benefits associated with the use of natural gas in all sectors of California's economy. To the extent that ultra-low NO_x natural gas trucks enter the market in the next few years and play an important role in the State's approach to meet future air quality and climate goals, it will be important to already have these potential reporting requirements and measures in place.

Ultimately, a key driver of fugitive emissions is our demand for oil and natural gas, which will likely have to decline significantly to meet our climate and air quality targets. As state policies continue pushing our evolution away from conventional oil and natural gas, they will also help to reduce emissions of methane from the production and distribution of fossil fuels. In particular, efforts to improve efficiency or electrify appliances, buildings, and vehicles will not only reduce energy use and CO_2 emissions, but also serve to reduce or avoid fugitive methane emissions from the production, and potentially transmission and distribution, of natural gas. In developing the Strategy, ARB and other agencies will consider whether fugitive methane emissions should be accounted for in cost/benefit calculations for various state energy and efficiency programs, and appropriate methods for potentially doing so.

Effectively Eliminate Disposal of Organic Materials at Landfills

Organic waste constitutes more than one-third of California's waste stream. Food waste alone accounts for about five million tons of landfilled organics each year. Efforts to divert organics from landfills, and to develop an organics infrastructure that makes best use of the material, are a key element of integrated strategies to increase production and access to renewable energy, reduce air pollution, improve agricultural soil health, and reduce GHG emissions from a broad array of sources throughout California.

California has clear goals to reduce waste, and to divert organic material from landfills and put it to beneficial use. The State has a target to reduce landfilling of solid waste by 75 percent in 2020 through the use of recycling, composting, and source reduction.

Additionally, the 2014 Scoping Plan Update called for eliminating disposal of organic materials at landfills, which has the potential to virtually eliminate methane emissions from landfills over time, once existing organic "waste-in-place" has decomposed. The Legislature has taken steps to increase organics diversion from landfills, through AB 1826 (Chesbro, Chapter 727, Statutes of 2014) and AB 1594 (Williams, Chapter 719, Statutes of 2014). This legislation represents important steps forward.

Building on this foundation, the Strategy will explore additional measures to accelerate organics diversion and GHG emission reductions to meet an initial goal of diverting 75 percent of organics from landfills through source reduction and organics recycling by 2020. This amounts to a 50 percent additional reduction from current levels, and is in line with existing goals set forth in AB 341 (Chesbro, Chapter 476, Statutes of 2011). Further, the Strategy will consider measures to meet a goal of diverting 90 percent of organics from landfills through source reduction and organics recycling by 2025 (80 percent reduction from current levels). Achieving these levels of diversion would effectively eliminate the disposal of organic materials in landfills in California, as called for in the Scoping Plan Update, by the middle of the next decade.

An important step, and an effective way to meet these targets, is to avoid wasting food or other organic material in the first place. The Strategy will explore research opportunities and potential approaches to reduce food waste. In addition to reducing GHG emissions, avoiding food waste saves money, effectively conserves the amount of energy and water that would have been used to produce the food, and conserves fuel in delivery and removal of waste.

The next step is to support the development of infrastructure for utilizing the additional organic waste. Achieving these targets will likely require at least 100 new or expanded facilities for utilizing diverted organic waste from landfills – through composting, anaerobic digestion, or other methods that advanced the State goals related to air quality, climate, energy, and soil sustainability. The Strategy will explore funding mechanisms, incentives, and other measures to expedite these facilities and phasing out organic disposal at landfills. One mechanism that will be considered is reforming CalRecycle's solid waste tipping fee to incentivize the diversion of organic material away from landfills and support the development of compost and anaerobic digestion facilities.

Finally, additional regulatory measures may be necessary to achieve these levels or complement potential state incentives or funding for organic waste infrastructure. In developing the Strategy, agencies will consider potential regulatory measures as an element of a comprehensive approach to effectively eliminate organics from landfills.

Even if we eliminate new organics in landfills, existing organic waste in landfills will remain a source of methane emissions for years to come. In developing the Strategy, ARB will work with CalRecycle, stakeholders, and experts to identify research needs and other efforts to develop potential measures to expand the use of best management practices and further reduce methane emissions from landfills by 2020 and through

2030. These measures could include upgrading landfill gas collection systems, improved post-closure maintenance, improved monitoring, and phased closure.

Significantly Cut Methane Emissions from Dairies

Agriculture, primarily dairies, is responsible for about 60 percent of California's methane emissions.[†] About equal levels of emissions come from manure management (primarily in flushwater lagoon systems at dairies) and the digestive processes of cows and other ruminant animals (enteric fermentation). Any potential strategies to reduce agricultural methane emissions should be based on a whole-system perspective in the California context, taking into account the lifecycle of emissions, energy and water use, economics, animal health/welfare, soil health, and water quality.

Methane emissions from manure management can be significantly reduced by capturing and destroying or utilizing methane from lagoons, switching from lagoon systems to solid manure management "scrape" systems (to avoid generating methane in the first place), and/or converting manure into renewable energy in anaerobic digesters. Anaerobic digesters can be used with manure from lagoons or scrape systems and may provide renewable electricity or natural gas that can be used to power farm equipment and vehicles, including milk trucks, which would further reduce air pollution and GHG emissions. Dairy manure can also be mixed with other organic materials – diverted from landfills or at wastewater treatment facilities, for example – and "co-digested," which may improve the performance or economics of anaerobic digestion projects in certain cases. Switching to scrape systems could potentially deliver significant water savings, along with improvements in water quality and soil health.

In developing the Strategy, ARB will work with CDFA, stakeholders, and experts to better understand the potential costs or environmental tradeoffs and broad array of benefits associated with various options to reduce methane emissions at dairies. The Strategy will identify necessary investments and other strategies to control manure methane emissions from the largest sources as quickly as possible – and no later than 2025. Those measures will likely include developing a methane capture or abatement standard, as called for in the Scoping Plan Update, as well as incentives and state funding to bring as many projects as possible online ahead of any potential regulation on existing sources.

Methane is also produced by the microorganisms involved in the digestive processes in the stomachs of ruminants, such as sheep, goats, buffalo and cattle – which is referred to as "enteric fermentation." Achieving the methane targets identified in this Concept Paper may be difficult or infeasible if emissions from enteric fermentation increase. Research on strategies to reduce methane emissions from enteric fermentation has

[†] The Animal Legal Defense Fund has petitioned ARB to measure and control animal agriculture methane emissions via ARB's Mandatory Reporting Rule and Cap-and-Trade Regulation. ARB continues to investigate this option and welcomes feedback on it as the planning process moves forward.

increased significantly in the past few years. Potential strategies may include breeding for lower methane-producing animals, microbial interventions, and nutrition and animal management.[32] The Strategy will describe existing research in this area and remaining gaps.

Maximize Resource Recovery from Wastewater Treatment Facilities

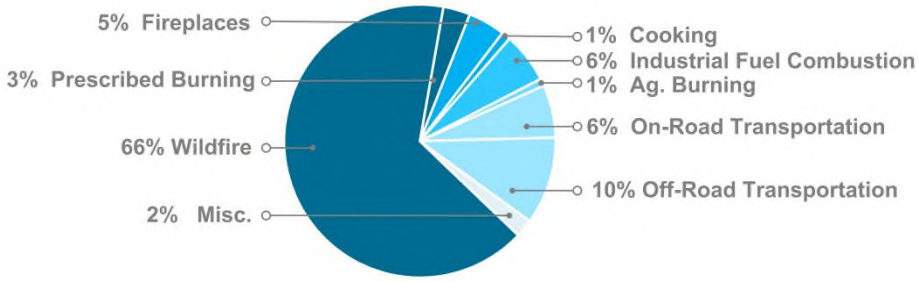
Wastewater treatment plants are used to treat or reclaim sewage or liquid waste streams from residential, commercial and industrial sources. These plants represent a relatively small amount of California's methane inventory (four percent). Most wastewater treatment plants already use anaerobic digestion in their processing, and many have large amounts of spare capacity to potentially take in new sources of waste. As such, wastewater treatment presents a tremendous opportunity to divert organics from landfills and utilize them for producing energy and soil amendments. Many of the treatment plants are located fairly close to population centers and could utilize potentially significant amounts of food and other organic waste streams that come from cities and towns.

Existing barriers limit or discourage wastewater treatment facilities from more fully recovering the energy and nutrient value that remains in organic waste. The Strategy will build on existing efforts to overcome these barriers and identify opportunities to expand the role that wastewater treatment plants can play in diverting organic waste from landfills and putting it to beneficial use while minimizing methane emissions.

Additionally, much of California's wastewater infrastructure is aging and vulnerable to climate change impacts, and due for renewal, retooling, and/or replacement before 2030. Many tens of billions of dollars will be invested in new infrastructure over that time frame, which could transform the wastewater sector and its business model into one that focuses not only on water quality, but also on maximum resource recovery from a wide array of waste streams and potential end products. ARB will work with the Water Resources Control Board to identify potential options to increase the role that wastewater treatment can play in reducing emissions of SLCPs.

Black Carbon Emission Reduction Concepts

Black carbon emissions are the State's third largest component of GHG emissions (see Figure 3 for California's black carbon emission sources), and as a component of diesel particulate matter, is among the most toxic and harmful air pollutants affecting health in our communities. Globally, black carbon emissions are responsible for millions of premature deaths each year. In California, health impacts are valued at tens of billions of dollars from smog-forming emissions such as NOx, black carbon and diesel particulate matter, every year.



California has done more than any other jurisdiction to reduce the emissions of particulate matter (PM) and black carbon. ARB and local air districts have developed programs to comply with federal air quality standards for PM. These include mandatory and voluntary rules to restrict residential wood-burning in fireplaces and wood stoves, as well as incentive programs to switch to cleaner burning devices. Additionally, district rules regulating commercial cooking and smoke management programs addressing agricultural, forest, and rangeland burning operations have reduced PM emissions. California has achieved significant emission reductions from diesel-fueled engines and vehicles through the implementation of the Diesel Risk Reduction Plan. California's clean fuel and in-use vehicle requirements for on- and off-road sources and complementary incentive programs have accelerated the switch to cleaner diesel equipment and cleaner vehicles, directly contributed to diesel PM emission reductions. As a result, ambient levels of black carbon in California are now 90 percent lower than in the early 1960s, despite the use of diesel fuel more than tripling over the same time period. Existing rules will cut them in half again by 2020.

If the rest of the world achieved similar levels of reductions, it would prevent millions of premature deaths each year and slow global warming by 15 percent. But the State still suffers from the nation's worst air quality, and many regions remain out of compliance with federal health-based ambient air quality standards. Complying with federal air quality standards and protecting public health in our State will require virtually eliminating smog-forming and particulate matter emissions from mobile sources in Southern California and the Central Valley by 2031.

Non-anthropogenic black carbon emissions (wildfires) account for more than half of the State's total black carbon emissions. While this source is difficult to control, it is critical to address as part of integrated climate and forest planning.

The impacts of black carbon on climate change vary by location and source, which complicates climate modeling and understanding of the climate forcing role that black carbon plays. Particulate matter emissions that include black carbon also inevitably include "brown carbon" (the light absorbing component of organic carbon, which is abundant in biomass burning), sulfur, and other particles that have varying impacts on regional climate. ARB is sponsoring research to advance the science on black carbon, as well as brown carbon. Results from this research will improve our understanding of

its impact on the climate, and inform ongoing efforts to further reduce emissions, address climate change, and improve public health.

In developing the Strategy, ARB will provide information on current research efforts, and lay out a research agenda that will identify additional actions to advance the science on black and brown carbon and incorporate this into our efforts to address SLCPs, as appropriate.

Continue to Lead on Reducing Diesel Black Carbon Emissions

California has done more than any jurisdiction in the world to reduce diesel emissions, but many areas in the State still suffer from poor air quality. According to the American Lung Association, California cities still rank as the top five in the country for ozone and particle pollution.[33]

State and local efforts will continue reducing diesel particulate matter emissions to comply with federal air quality standards and further protect public health, which will further reduce black carbon emissions, as well. ARB is working with the State's transportation and energy agencies, as well as its economic development office, local partners, and stakeholders to develop a comprehensive, integrated plan – the California Sustainable Freight Strategy – that will enhance system efficiency; deploy zero and near-zero emission freight equipment powered by renewable energy sources; provide reliable velocity while increasing safety, mobility and capacity; and improve the competitiveness of our logistics system. Additionally, ARB continues to update the State Implementation Plan, including a plan in 2016 that will outline actions to achieve federal air quality standards by 2032. Emission reduction measures identified in these ongoing processes will be incorporated in the SLCP Strategy.

In developing the Strategy, ARB will work with other agencies to align efforts to improve air quality and reduce black carbon emissions, and identify any additional diesel black carbon-specific measures that may not otherwise be captured through existing efforts. While existing policies and processes effectively target particulate matter and black carbon emissions from on-road sources, additional efforts are needed to drive reductions from off-road sources, including farm and construction equipment, trains and railroad operations, cargo handling equipment, and shipping.

Reduce Black Carbon Emissions from Biomass Burning

The State and local air districts have a number of measures in place to reduce particulate matter emissions from biomass burning, which have also resulted in significant reductions of black carbon. State law restricts agriculture burning in specific parts of California. All large air districts in the State have adopted mandatory and voluntary rules restricting wood-burning in residential fireplaces and heaters. In fact, the Bay Area Air Quality Management District is considering a new rule to ban all wood burning devices in new construction and restrict the sale of buildings with old fireplaces, stoves or other wood-burning devices that fail to meet United States Environmental

Protection Agency (U.S. EPA) emission standards. Air districts also administer incentive programs for residents to replace their old wood burning devices with new, cleaner options. ARB will coordinate with local agencies and identify potential options to further reduce particulate matter and black carbon emissions from biomass burning from major sources, including wildfire, agricultural burning, open pile burning, and commercial and residential cooking and fireplaces, among others. ARB will explore research related to how we can most effectively prioritize areas where the use of prescribed fire will have the greatest reduction in wildfire risk, and associated net black carbon impacts, at the lowest cost, and with the least impact to residents at the urban-wildland interface.

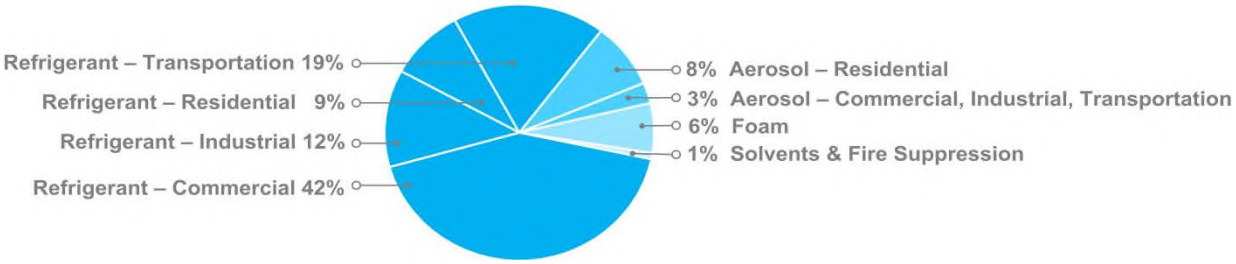
Wildfires account for the majority of black carbon emissions in California. No single wildfire may be preventable, but improved management can reduce the incidence and severity of wildfires in California, which can offer climate benefits by both strengthening our forests as carbon stocks and sinks, and reducing black carbon (and brown carbon) emissions from wildfires. Additionally, the impacts of climate change are expected to make wildfires more frequent and severe, and our forests need to increasingly be managed with climate change impacts in mind.

The Scoping Plan Update called for developing a "Forest Carbon Plan" in 2016 to set quantitative greenhouse gas planning targets for the State's forests and identify actions to meet them. ARB is part of an inter-agency working group of Federal and State agencies that is currently developing the Plan. The working group is reviewing forest practice regulations and recommendations for best management practices and potential additional regulatory actions to minimize GHG emissions and enhance carbon storage associated with silvicultural treatments. Potential management practices to minimize GHG emissions could include measures that would enhance wild land fire prevention and suppression, resulting in avoidance of direct black carbon emissions.

Improved management of woody biomass in general – from forest residues, agricultural waste, or other sources – can reduce black carbon emissions and provides an opportunity to generate renewable energy and economic development in rural parts of the State. As for other organic waste streams, the Strategy will explore options to put woody biomass to beneficial use and avoid black carbon emissions that would otherwise result from burning. One option may be pyrolysis of woody biomass, which generates energy and biochar, and which can be used to sequester carbon in soils and improve soil fertility.[34,35,36,37] Current analyses suggest that biochar could be used to sequester significant volumes of CO_2 globally,[38] but the benefits of large-scale projects have not been demonstrated or quantified, and several research gaps remain. Despite the uncertainty, several carbon trading entities have developed or are developing protocols for biochar projects.[39,40] The potential benefits from these projects will be investigated, and additional research or demonstration projects will be identified to improve our understanding of the potential role biochar may play in addressing an integrated set of air pollution, climate, energy, soil and resource issues.

F-Gas Emission Reduction Concepts

Fluorinated gases are the fastest growing source of GHG emissions both globally and in California (see Figure 4 for California's F-gas emission sources). They include ozone-depleting substances that are being phased out under the Montreal Protocol, and their primary substitute, hydrofluorocarbons (HFCs). Most F-gas emissions come from leaks of these gases in refrigeration and air-conditioning systems. F-gases are also emitted when used in aerosol propellants and fire suppressants at the time of application, and slowly emitted from polyurethane foam insulation when used as foam-expanding agents.



* Does not include two long-lived HFCs with negligible emissions.

Many F-gases are hundreds, or thousands, of times more potent than CO_2. For an increasing number of them, low-GWP alternatives are entering the market and becoming more cost-effective. Many of them can be easily captured or destroyed at the end-of-life, and are even required to be, but due to the lack of incentive and difficulty of enforcement, they often are not. Reducing F-gas emissions from many sources are among the most cost-effective opportunities to reduce GHG emissions.

California is among the leaders in reducing F-gas emissions. It is the only subnational entity with an inventory of F-gas emissions, and early action measures adopted under AB 32, including the Refrigerant Management Program for stationary sources, will reduce F-gas emissions by an estimated six million metric tonnes of CO_2-equivalent ($MMTCO_2$-e) by 2020.

California's efforts to reduce emissions of F-gases are part of a broader set of national and international commitments to phase down the production and use of HFCs. President Obama, China President Xi Jinping, and leaders of the G-20 countries have agreed to work together and through the Montreal Protocol to phase down the production and consumption of HFCs. The U.S. EPA can impose federal bans on F-gases under the Significant New Alternatives Policy (SNAP) Program. The agency has proposed, but not yet adopted, bans on specific HFCs with very high GWPs used in new commercial refrigeration systems, the manufacture of polyurethane foam, and in new light-duty motor vehicle AC systems. The European Union has adopted leading F-gas regulations that will phase down the production and import of HFCs by almost 80 percent from 2015 levels in 2030.[41,42]

Given this national and international context, California can accelerate broader action on F-gas emissions by continuing to build on its leading efforts. New measures developed in California can grow markets for low-GWP alternatives, and can provide an important national and international signal to build the case for action. The Strategy will consider several additional efforts to reduce the use and emissions of high-GWP F-gases from several sources.

Reduce the Use of HFCs in New Refrigeration and Air-Conditioning Equipment by At Least 80 Percent by 2030

The Scoping Plan Update called for California to work with the U.S. Environmental Protection Agency and other partners to develop programs to phase-down HFC production and import by about 80 percent by 2030. This aligns with commitments by the U.S., Mexico, Canada, China, European Union, India, and others to phase-down the production of HFCs under the Montreal Protocol. Proposed amendments to the Montreal Protocol are currently under negotiation.[43,44]

A global phase-down under the Montreal Protocol is necessary to alleviate much of the burden that the use of these gases imposes on our climate, and California will support international efforts to address the issue. Still, California can lead by taking its own steps to reduce the use of HFCs in the State as quickly as possible. Existing measures adopted under AB 32 are projected to reduce HFC emissions in California by 30 percent below "business as usual" levels in 2030. Proposed federal rules would reduce HFC emissions by another 10 percent in California in 2030.

The Strategy will explore additional steps that California can take to reduce the use of HFCs in the State by at least 80 percent by 2030. HFC emission reductions could be achieved through sector specific prohibitions, where feasible and cost effective alternatives are available, by imposing a mitigation fee on sales of high-GWP HFCs, or other potential options. (Note that F-gas emission reductions partially lag reductions in their use, due to the long life of the existing stock of equipment that still contain high-GWP F-gases. Therefore, an 80 percent reduction in the use of F-gases by 2030 would not reduce their emissions by as much as 80 percent in that same year.)

Remove High Global Warming Potential Gases from Foams, Aerosols, and Transportation

In particular, the use of HFCs in foams, aerosols, and transportation could be quickly addressed. The majority of insulating foam and aerosol propellants that have historically used high-GWP F-gases has already transitioned to low-GWP substitutes. ARB regulations currently ban consumer product aerosol propellants with a GWP greater than 150 in most products, and the U.S. EPA has proposed federal prohibitions on the use of high-GWP HFCs in certain insulating foam applications and aerosol propellants.

In developing the Strategy, ARB will consider measures, including bans, to transition the remaining insulating foams and aerosol propellant consumer products using HFCs to low-GWP alternatives as soon as possible. Additionally, ARB will consider developing regulations to prohibit the use of high-GWP refrigerants in air conditioning and refrigeration systems for heavy-duty motor vehicles, if such prohibitions are not enacted at the federal level.

Reduce Leaks from Existing Equipment and at End-of-Life

Phasing out the use of these highly potent gases is necessary to reduce their emissions, but even then, strong measures are needed to ensure best practices are employed during the use and end-of-life of appliances, in order to prevent the release of F-gases for decades to come. Leakier systems may have lower upfront capital costs, but higher operating costs – due to the greater need for repairs and to replenish leaking refrigerant. At the end of life, while requirements exist for scrappers to capture F-gases, it is often easier to just "cut-the-line," and vent the gas. These are problems that may not be easily solved through regulation.

ARB will consider stronger regulations and enforcement as part of the Strategy to reduce F-gas emissions, and will also consider additional incentives, funding, and collaborative efforts that can be taken with the private sector to significantly reduce emissions from F-gases during their use and end-of-life. This will include reviewing utility-based incentive programs, and considering the costs and benefits of measures that could be taken to strengthen them, expand them, link them with energy efficiency programs in cases where the use of low-GWP refrigerants can also reduce energy use, or otherwise adjust them to ensure that appliances with low-GWP gases are incentivized, and gases from old and leaking appliances are increasingly captured, recycled, or destroyed.

Target Early Action to Significantly Reduce F-gas Emissions from Commercial Refrigeration

Commercial refrigeration, which is the source of about 40 percent of California's F-gas emissions, may provide a ready test case for a productive, collaborative approach to significantly reduce F-gas emissions. President Obama recently announced a coordinated set of public and private sector commitments to reduce HFC emissions,[45] mainly from the commercial sector, and cost-effective alternatives (including CO_2) are available for many applications in many locations.[46] Emission reductions in California on the order of several $MMTCO_2$-e per year may be available at a cost of a few dollars per tonne.

But the requirements, incentives and funding mechanisms need to align with the commitment of the private sector, in order to capture this opportunity. In developing the Strategy, ARB will work with other agencies, stakeholders, experts, and others to identify potential mechanisms to accelerate the transition to the use of recycled refrigerant or low-GWP alternatives as quickly as possible. While commercial

refrigeration operations cover a wide array of businesses and applications, ARB will look to identify collaborative approaches to overcome barriers and transition large commercial refrigeration systems to low-GWP alternatives as soon as possible, and no later than 2025.

ARB will consider developing regulatory requirements to use low-GWP refrigerants in new commercial refrigeration systems by feasible effective dates, as well as potential future bans or other regulatory requirements or programs for existing systems. Additionally, the Strategy will explore the potential scope and cost-effectiveness of potential incentives to:

- Remove high-GWP refrigerants from existing equipment and replace (retrofit) with low-GWP refrigerants in the same equipment.
- Offset some or all of the higher cost that might be associated with replacing older high-GWP refrigeration equipment with new, low-GWP refrigeration systems.
- Install low-GWP refrigeration systems at new facilities.
- Link with energy efficiency programs in cases where low-GWP refrigerants can reduce energy use. For example, low-GWP refrigerants such as ammonia, carbon dioxide, and hydrocarbons have been shown to reduce energy consumption between 5 and 35 percent compared to HFC refrigerants, with a corresponding decrease in electricity use and GHG emissions.[47]
- Encourage the greater use of recycled refrigerants for air conditioning and refrigeration buildings.
- Recover and destroy F-gas refrigerants no longer produced.

Showing the Way to 2^{o}C

California is committed to building on its ongoing leadership to cut air pollution and greenhouse gas emissions by developing a comprehensive, effective plan to significantly reduce SLCP emissions in the State through 2030. Doing so, in conjunction with strong action to immediately cut emissions of CO_2, is the only way to stabilize global warming below 2^{o}C and provide near-term climate benefits that can help reduce the disproportionate climate impacts that are likely to be felt in the developing world. Accordingly, in his 2015 Inaugural Address, Governor Brown called for California to "reduce the relentless release of methane, black carbon and other potent pollutants across industries," as a key part of his plan to show the world the path to limiting global warming to no more than 2^{o}C.[48]

The concepts described in this paper represent an initial set of ideas that deserve conversation and exploration, but it is not meant to be exhaustive. We welcome comments that will advance California's goal of demonstrating that emission reductions can be achieved in ways that are not only affordable, but also beneficial to the State economy and the well-being of its residents.

References

[1] Ramanathan V, Xu Y. The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues. Proceedings of the National Academy of Sciences of the United States of America. 2010;107 (18):8055–8062. [PMC free article]

[2] IGSD (2013) Primer on Short-Lived Climate Pollutants, Institute for Governance and Sustainable Development, February 2013. http://igsd.org/documents/PrimeronShort-LivedClimatePollutantsFeb192013.pdf

[3] Akbar, Sameer; Ebinger, Jane; Kleiman, Gary; Oguah, Samuel. 2013. *Integration of short-lived climate pollutants in World Bank activities: a report prepared at the request of the G8*. Washington DC ; World Bank. http://documents.worldbank.org/curated/en/2013/06/18119798/integration-short-lived-climate-pollutants-world-bank-activities-report-prepared-request-g8
web.stanford.edu/group/efmh/jacobson/Articles/VIII/BCClimRespJGR0710.pdf

[4] Molina M, Zaelke D, Sarma KM, Andersen SO, Ramanathan V, Kaniaru D. Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America*. 2009;106(49):20616-20621. doi:10.1073/pnas.0902568106.
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2791591/

[5] IGSD (2012) The Need for Speed: Reducing Short-Lived Climate Forcers and Perfecting Deliberate Carbon Removal Strategies Complement CO_2 Reductions, Institute for Governance and Sustainable Development, October 25. http://www.igsd.org/short-lived-climate-pollutants/index.php

[6] UNEP (2014) Time to Act (To Reduce Short-Lived Climate Pollutants), The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants, United Nations Environment Programme, Second Edition, May. http://www.unep.org/ccac/Publications/Publications/TimeToAct/tabid/133392/Default.aspx

[7] Velders et al (2009) The Large Contribution of Projected HFC Emissions to Future Climate Forcing, *Proceedings of the National Academies* **106** (27), 10949-10954.
www.pnas.org/cgi/doi/10.1073/pnas.0902817106

[8] Velders et al (2014) "Growth of climate change commitments from HFC banks and emissions", G. J. M. Velders, S. Solomon, and J. S. Daniel. *Atmospheric Chemistry and Physics*, 14, 4563–4572, 2014. doi:10.5194/acp-14-4563-2014. www.atmos-chem-phys.net/14/4563/2014/.

[9] Ramanathan V, Xu Y. The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues. Proceedings of the National Academy of Sciences of the United States of America. 2010;107 (18):8055–8062. [PMC free article]

[10] UNEP (2014) Time to Act (To Reduce Short-Lived Climate Pollutants), The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants, United Nations Environment Programme, Second Edition, May. http://www.unep.org/ccac/Publications/Publications/TimeToAct/tabid/133392/Default.aspx

[11] Under a scenario where only measures to reduce CO_2 emissions are employed to limit atmospheric concentrations of CO_2 to no more than 450 parts per million by the end of this century (equivalent to a 2^oC scenario), average global warming is reduced by about 0.15^oC by 2050.
UNEP and WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone, United Nations Environment Programme and World Meteorological Association.
http://www.unep.org/dewa/Portals/67/pdf/BlackCarbon_report.pdf

[12] Ramanathan, V. and Yangyang Xu (2010) The Copenhagen Accord for Limiting Global Warming: Criteria, Constraints, and Available Avenues, *Proceedings of the National Academies of Sciences* **107** (18), pp.8055-8062. http://www.pnas.org/content/107/18/8055

[13] Xu, Y., D. Zaelke, G. J. M. Velders, and V. Ramanathan (2013), The role of HFCs in mitigating 21st century climate change, *Atmos. Chem. Phys.*, 13(12), 6083–6089

[14] Quinn et al (2008) Short-lived pollutants in the Arctic: Their impact and possible mitigation strategies, *Atmospheric Chemistry and Physics* **8**, 1723-1735. http://www.atmos-chem-phys.net/8/1723/2008/acp-8-1723-2008.html

[15] UNEP (2014) Time to Act (To Reduce Short-Lived Climate Pollutants), The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants, United Nations Environment Programme, Second Edition, May. http://www.unep.org/ccac/Publications/Publications/TimeToAct/tabid/133392/Default.aspx

[16] Francis, J. A. and S. J. Vavrus. 2012. Evidence linki ng Arctic amplification to extreme weather in mid-latitudes. Geophysical Research Letters 39.
[17] Screen, J. A. and I. Simmonds. 2013. Exploring links between Arctic amplification and mid-latitude weather. Geophysical Research Letters 40(5):959-964.
[18] Ramanathan, V. and Yangyang Xu (2010) The Copenhagen Accord for Limiting Global Warming: Criteria, Constraints, and Available Avenues, *Proceedings of the National Academies of Sciences* **107** (18), pp.8055-8062. http://www.pnas.org/content/107/18/8055
[19] Hu, A., Y. Xu, C. Tebaldi, W. M. Washington, and V. Ramanathan (2013), Mitigation of short-lived climate pollutants slows sea-level rise *Nature Climate Change* 3(5), 1–5, doi:10.1038/nclimate1869
[20] UNEP and WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone, United Nations Environment Programme and World Meteorological Association. http://www.unep.org/dewa/Portals/67/pdf/BlackCarbon_report.pdf
[21] Shindell et al. (2012) Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security, *Science* **335**, 183 (2012). http://www.sciencemag.org/content/335/6065/183
[22] Ault AP, Williams CR, White AB, Neiman PJ, Creamean JC, Gaston CJ, Ralph FM, Prather KA. Detection of Asian Dust in California Orographic Precipitation. Journal of Geophysical Research - Atmospheres (2011), 116, D16205
[23] UNEP (2014) Time to Act (To Reduce Short-Lived Climate Pollutants), The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants, United Nations Environment Programme, Second Edition, May. http://www.unep.org/ccac/Publications/Publications/TimeToAct/tabid/133392/Default.aspx
[24] Hu et al (2013) Mitigation of Short-Lived Climate Pollutants Slows Sea-Level Rise, *Nature Climate Change* **3** 730-734. http://www.nature.com/nclimate/journal/v3/n8/full/nclimate1869.html
[25] Ramanathan et al (2013) Black Carbon and the Regional Climate of California, Report to the California Air Resources Board, Contract 08-323, April 15. http://www.arb.ca.gov/research/single-project.php?row_id=64841
[26] Wallack, J. and Veerabhadran Ramanathan (2009) The Other Climate Changers: Why Black Carbon and Ozone Also Matter, *Foreign Affairs*, September/October 2009, pp. 105-113. http://www.foreignaffairs.com/articles/65238/jessica-seddon-wallack-and-veerabhadran-ramanathan/the-other-climate-changers
[27] NEA (2014) Summary of Proposed Action Plan for Norwegian Emissions of Shortlived Climate Forcers, Norwegian Environment Agency, March. http://www.miljodirektoratet.no/en/Publications/2014/March-2014/Summary-of-proposed-action-plan-for-Norwegian-emissions-of-shortlived-climate-forcers/
[28] AB 1532 (Pérez, Chapter 807), SB 535 (De León, Chapter 830), and SB 1018 (Senate Budget Committee, Chapter 39) established the GHG Reduction Fund to receive Cap-and-Trade auction proceeds.
[29] Fiore, A. M., J. J. West, L. W. Horowitz, V. Naik, and M. D. Schwarzkopf (2008) Characterizing the tropospheric ozone response to methane emission controls and the benefits to climate and air quality, J. Geophys. Res., 113, D08307, doi:10.1029/2007JD009162.
[30] West, J. J., A. M. Fiore, L. W. Horowitz, and D. L. Mauzerall (2006), Global health benefits of mitigating ozone pollution with methane emission controls, Proc. Natl. Acad. Sci. U.S.A., 103, 3988–3993.
[31] Fiore, A. M., F. J. Dentener, O. Wild, C. Cuvelier, M. G. Schultz, P. Hess, C. Textor, M. Schulz, R. M. Doherty, L. W. Horowitz, I. A. MacKenzie, M. G. Sanderson, D. Shindell, D. S. Stevenson, S. Szopa, R. Van Dingenen, G. Zeng, C. Atherton, D. J. Bergmann, I. Bey, G. Carmichael, W. J. Collins, B. Duncan, G. Faluvegi, G. Folberth, M. Gauss, S. Gong, D. Hauglustaine, T. Holloway, I. S. A. Isaksen, D. Jacob, J. E. Jonson, J. W. Kaminski, T. J. Keating, A. Lupu, E. Marmer, V. Montanaro, R. J. Park, G. Pitari, K. J. Pringle, J. A. Pyle, S. Schroeder, M. G. Vivanco, P. Wind, G. Wojcik, S. Wu, and A. Zuber (2009), Multimodel estimates of intercontinental source-receptor relationships for ozone pollution, J. Geophys. Res., 114, D04301, doi:10.1029/2008JD010816.
[32] Ripple, W.J., P. Smith, H. Haberl, S. A. Montzka, C. McAlpine and D.H. Boucher. 2014. Ruminants, climate change and climate policy. Nature Climate Change. 4: 2-4.
[33] ALA (2014) State of the Air, American Lung Association. http://www.stateoftheair.org/
[34] Lehmann, J., Gaunt, J., Rondon, M., 2005. Bio-char sequestration in terrestrial ecosystems- a review. Mitigation and adaptation strategies for global change.

[35] Laird, A.D., 2008. The charcoal Vision: A win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality.Agronomy Journal 100, 178-181.
[36] Matthews, J.A., 2008. Carbon negative biofuels. Energy Policy 36, 940-945.
[37] Woolf, D., 2008. Biochar as a soil amendment: A review of the environmental implications.In: Swansea.
[38] Sohi, S1.Loez-Capel, E2., Krull, E3., Bol, R4., 2009. Biochar's roles in soil and climate change: A review of research needs. CSIRO Land and Water Science Report 05/09, 64 pp..
[39] Koper, T. P. Weisberg, A. Lennie, K. Driver, H.Simons, M. Rodriguez, D. Reed, S. Jirka and J. Gaunt. 2010 Methodology for Biochar Projects V1.0. American Carbon Registry.
[40] CAPCOA GHG Exchange. 2014. Biochar Production for Project Reporting Protocol: GHG Emission reduction Accounting. Version 3.0.
[41] EC (2014) European Commission (EC), April 16, 2014 "Regulation (EU) No 517/2014 of the European Parliament and of the Council on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 alternatives". http://ec.europa.eu/clima/policies/f-gas/legislation/documentation_en.htm
[42] EC (2006) European Commission (EC), May 17, 2006 "Commission Regulation (EC) No 842/2006 of the European Parliament and of the Council on certain fluorinated greenhouse gases". http://ec.europa.eu/clima/policies/f-gas/legislation/documentation_en.htm
[43] UNEP, 2013. United Nations Environment Programme (UNEP), "Proposed amendment to the Montreal Protocol submitted by Canada, Mexico and the United States of America", June 24, 2013. Available at: http://conf.montreal-protocol.org/meeting/oewg/oewg-33/presession/PreSession%20Documents/OEWG-33-3E.pdf (accessed 28 January 2015).
[44] UNEP, 2015. United Nations Environment Programme (UNEP), "Proposed amendment to the Montreal Protocol submitted by India", April 22, 2015. http://conf.montreal-protocol.org/meeting/oewg/oewg-35/presession/default.aspx
[45] Executive Office of the President of the U.S., Council of Environmental Quality, Fact Sheet released September 16, 2014, "FACT SHEET: Obama Administration Partners with Private Sector on New Commitments to Slash Emissions of Potent Greenhouse Gases and Catalyze Global HFC Phase Down". https://www.whitehouse.gov/the-press-office/2014/09/16/fact-sheet-obama-administration-partners-private-sector-new-commitments-
[46] Operating costs for CO_2-charged systems may be higher in hotter climates, due to the relatively low boiling point of CO_2. In cooler climates, CO_2-based systems may cut energy and operating costs for commercial facilities.
[47] Wang, et al., 2009. "Review of secondary loop refrigeration systems", Kai Wang, Magnus Eisele, Yunho Hwang, and Reinhard Radermacher. International Journal of Refrigeration 33 (2010) 212-234. Available at: doi:10.1016/j.ijrefrig.2009.09.018 and www.elsevier.com/locate/ijrefrig
[48] Edmund G. Brown, Jr. Inaugural Address, Remarks as Prepared, January 5, 2015. http://gov.ca.gov/news.php?id=18828