Climate Resolve

Innovate. Advocate. Achieve. **Together.**

May 17, 2022

Liane M. Randolph, Chair
California Air Resources Board
1001 I Street
Sacramento, CA 95814

RE: Comments on the Draft 2022 Climate Change Scoping Plan Update

Dear Chair Randolph and Members of the California Air Resources Board (CARB):

Climate Resolve congratulates CARB for achieving its 2020 greenhouse gas (GHG) emissions reduction target of returning to 1990 levels four years earlier than mandated by AB 32.[1] It is worthy of recognition and a springboard for future success. We must also recognize the challenges ahead for California and CARB. As the assessment in the Draft 2022 Scoping Plan Update (the Update) shows, meeting the SB 32 target of 40% below 1990 levels by 2030 is proving difficult. We are hopeful that CARB will recognize the many opportunities that California can unlock in accelerating its goal to meet 2030 and 2045 carbon neutrality goals.

For the past decade, Climate Resolve has been working to make Los Angeles more resilient in the face of climate change. In addition to the more obvious Energy and Transportation sector emissions reductions opportunities, we recognize that the built environment also presents a significant opportunity for reducing and removing greenhouse gas emissions, and not only in the form of carbon sequestration. We have been busy removing and reducing the global warming impacts of GHGs by not only planting trees that sequester carbon dioxide, but also by coating our streets and rooftops with high albedo reflective materials. **Cool streets and cool roof initiatives utilize high albedo surfaces to reflect**

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[1] Science Direct. 2020. Assessing California's Progress Towards its 2020 Greenhouse Gas Emissions Limit. https://www.sciencedirect.com/science/article/abs/pii/S0301421519308018#:~:text=California%20law%20requires%20statewide%20greenhouse,%2Dthan%2Dexpected%20emissions%20reductions.

sunlight back into space, bypassing heat trapping GHGs and mitigating the global warming impacts of GHGs.[2]

These cost-effective solar radiative forcing strategies work already today and are sorely missing from the Update.

According to Dr. Xiulin Ruan of Purdue University, you only need to coat less than 1% of the Earth's surface with reflective materials and you can reverse global warming.[3] Additionally, a mixed-method model conducted by Edith de Guzman at the University of California, Los Angeles combined high albedo street surfaces with various tree canopy schemes resulting in significant decreases in ambient temperatures.[4] Furthermore, placing high albedo materials on roofs has similarly led to promising effects on lower ambient temperatures.[5] The ambient temperature cooling impact of high albedo surfaces provides co-benefits for climate resiliency, by counteracting climate change-driven increases in extreme heat, and in local air quality, since heat is a driving factor in ground-level ozone formation. Shifting the scope of the Update to include innovations that cancel the warming effect of GHGs and reduce the global warming potential of GHGs can go a long way to accelerate the speed in which CARB achieves its goals.[6]

We're not the only ones identifying the need to shift the priorities that shape policy and action. There's a growing recognition from experts across the globe, too. According to the United Nations Environment Programme (UNEP) 2021 Emissions Gap Report, the consensus is that, globally, "To keep global warming below 1.5°C this century, the world needs to urgently put additional policies and action in place to almost halve annual greenhouse gas emissions in the next eight years."[7]

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[2] Hammerschlag, Roel. 2020. Cool Roof Albedo Effect Memo. https://drive.google.com/file/d/13xq4c58N7DbLzGjcxukDdBR7E0h54eMT/view?usp=sharing

[3] PBS Newshour. October 2021. Can the World's Whitest Paint Save the Earth? https://www.pbs.org/newshour/show/can-the-worlds-whitest-paint-save-the-world

[4] Guzman, Edith B., et al. 2022. Increasing Trees and High Albedo Surfaces Decreases Heat Impacts and Mortality in Los Angeles. https://link.springer.com/article/10.1007/s00484-022-02248-8

[5] Krayenhoff, Scott E. 2010. Impacts of Urban Albedo Increase on Local Air Temperature at Daily-Annual Scales. https://journals.ametsoc.org/view/journals/apme/49/8/2010jamc2356.1.xml

[6] The World Bank Group. 2020. Primer for Cool Cities: Reducing Excessive Urban Heat. https://drive.google.com/file/d/1zpplrWkJUl2VFtoeZP5lKsGQfDbQZgbd/view?usp=sharing

[7] United Nations Environment Programme. 2021. The Heat is On: Emissions Gap Report 2021. https://wedocs.unep.org/bitstream/handle/20.500.11822/37001/EGR21_HOEN.pdf

Additionally, CARB has shifted priorities before. AB 32 was successful because CARB continually analyzed its business-as-usual approach and intervened when necessary, with forward-looking strategies. As the California Senate Environmental Quality Committee concluded in 2018, “Having an independent, retrospective analysis on previous scoping plans is a key step to determining where the modeling and assumptions in those plans have not been accurate, where programs in those plans have under-or over-performed on GHG emissions reductions, and where there may be any systematic biases or patterns where such forecasts turned out to be incorrect.”[8] Now, more than ever, it is crucially necessary to evaluate persisting shortcomings in the Update and change course to include additional feasible strategies.

A complementary strategy to the buildings and infrastructure considerations of the Sustainable Communities Strategy, the heat impacts considerations of the Public Health Strategy, and the cover-related considerations of the Natural and Working Lands Strategy, namely the developed land category, would look to adapt our existing extensive street grid and buildings to increase albedo of hardscape surface materials and carbon sequestration by trees. By increasing solar radiative forcing of developed land, these higher albedo surfaces would reduce the greenhouse effect that drives climate change as well as provide additional co-benefits from reduced ambient temperatures.

We propose that CARB include in Appendix E, G and I, an analysis of the GHG emissions reductions potential equivalent associated with aggressive and sustained efforts to install high albedo surfaces on public streets and building rooftops, and urban greening.

The Update does a good job analyzing the interrelated connection between compact development and transportation options in Appendix E. However, in its GHG analysis of Appendix I, it misses a blatant opportunity to incorporate the impact to the global warming potential of GHGs of static physical infrastructure which makes up the non-vegetated portions of developed lands. This analysis should be incorporated throughout Appendix E, G and I, where feasible, and should have a stand-alone vision, objectives and metrics.

Due to this policy gap and opportunity, we offer the following recommendations:

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[8] CA Senate Environmental Quality Committee. Sacramento 2018. California’s Cap-and-Trade Program: ARBs 2018 Scoping Plan—Oversight Hearing Background Document. https://senv.senate.ca.gov/sites/senv.senate.ca.gov/files/hearing_background_final.pdf

1. CARB Should Incorporate New Albedo-Related Solar Forcing Assumptions into its GHG Models in Appendix I

Increases in the albedo of developed surfaces, such as streets and roads, are associated with increased solar radiative forcing, and reduced global warming potential of existing greenhouse gasses in the atmosphere. CARB should include the greenhouse gas reduction equivalent of high-albedo surfaces in its GHG models and potential pathways to reaching carbon neutrality.

Cool surfaces mimic the reflective capacity of glaciers at the poles, or the sunshield provided by a marine layer. They reflect sunlight back to space eliminating the production of longwave radiation (heat) which gets trapped by GHGs in the atmosphere contributing to global warming. High albedo materials send more heat back to space than they absorb and provide a promising pathway to reducing the greenhouse gas effect, the source of climate change.

2. CARB Should Add Focus on GHG Reductions from Mode Shift and Reduced Energy Demand Associated with Direct Cooling of Existing Street Grids and Adjacent Buildings from Cool Surface Deployment in Appendix E and G

We know that people who choose to drive as the primary way of getting from point A to point B are responsible for 40% of GHG emissions in the state, which makes transportation a major focus area of the Update. Driving creates multiple problems: dangerous conditions for pedestrians and alternative mobility users, polluting ground-level emissions, waste heat from internal combustion engines, and the release of heat trapping GHGs that accumulate in the atmosphere. A growing method to entice people out of their cars is by making the public right-of-way safer and more comfortable to navigate using alternative mobility options. Reducing vehicle miles traveled (and GHGs) through street interventions like cool paving has a cascading series of positive effects on the environment, infrastructure, public health, and the economy.

An example of a successful partnership exploring the urban cooling potential of cool surfaces has been our collaboration with the City of Los Angeles. It has led to the first-of-its-kind cool roof ordinance and coating hundreds of miles of street pavement with reflective high albedo material. CARB should include in the Update the following secondary-effect GHG benefits of cool surfaces that are achieved by reducing ambient temperature: (1) reduced driving from mode shift by making alternative mobility options more appealing; and (2) reduced energy needs for cooling buildings.

3. CARB Should Analyze the Carbon Sequestration Associated with Improved Vitality of Urban Greening from Cool Streets and Cool Roofs in Appendix I

A primary contributor to the urban heat island effect is lack of trees and vegetation. The reasons driving this deficiency are many, but it is well documented that neighborhoods that lack trees are hot during the day and even hotter at night. Driving this excessive heat are heat-absorbing and exposed surfaces like pavement and roofs. These surfaces absorb more heat that they reflect leading to uncomfortable temperatures at the street level and dispelled heat ends up getting trapped in the atmosphere contributing to global warming. Furthermore, the heat that radiates from surfaces like pavement and roofs puts a strain on urban trees, reducing the vitality of urban forests and ultimately limiting the carbon sequestration potential of urban trees.

The federal Infrastructure Investment and Jobs Act will steer hundreds of millions of dollars to California to address extreme heat. In the past two years, there have been historic amounts of funding dedicated to urban greening efforts by the state. There are currently over $1.3 billion available funds for urban greening. Additionally, the state has allocated $800 million to fund community resilience and extreme heat. This funding will increase in 2022 as the state is going on year two of a budget surplus.

Incorporating cool streets and cool roofs alongside urban greening projects can result in a factor multiplier for the carbon sequestration potential of urban trees. This interrelationship should be incorporated into the metrics and models that CARB uses to account for the carbon sequestration potential of urban trees.

The recommendations identified in this comment letter have great potential to remove and reduce GHG emissions and global warming potential. CARB should shift its focus to embrace these integrated solutions that offer a host of co-benefits and accelerate the speed in which it reaches 2030 and 2045 carbon neutrality. We agree with CARB when they suggest that "shifting California's development patterns and transportation systems is an opportunity to address existing injustices by making livable, affordable homes with multi-modal connections to jobs, services, open space, and education available to all Californians, not just the white and the wealthy." However, CARB should also recognize that this strategy has come up way short and has unnecessarily extended the timeframe for California to meet its

2030 and now, 2045 goals. Transformation of this sort takes time, precious time that CARB cannot afford.

The time is now to shift focus and reduce GHGs and GHG potential in the most practical of ways, while pursuing transformational impact. Thank you for your attention on this matter. If you have any questions, I can be reached at jparfrey@climateresolve.org.

Sincerely,

Jonathan Parfrey
Executive Director

Attachment: Cool Roof Albedo Effect Memo

Hammerschlag LLC

MEMO

Subject: **Cool roof albedo effect**

From: Roel Hammerschlag

To: Jonathan Parfrey, Climate Resolve
Seth Jacobson, Climate Resolve
Thelma Briseno, Climate Resolve

Date: November 24, 2020

Doc. no.: CR-003(d)

Background

Climate Resolve is evaluating residential, commercial, and industrial cool roof retrofits as a global warming mitigation measure. Conventionally, global warming impact of a cool roof retrofit is ascribed only to the greenhouse gases (GHGs) avoided by reducing HVAC energy consumption. However, the increased albedo of a cool roof *directly* reduces radiative forcing of climate, complementing the indirect reduction to radiative forcing due to the avoided GHGs.

Climate Resolve has requested that Hammerschlag LLC (HLLC) quantify and compare the relative contributions of avoided GHGs due to a cool roof retrofit (“HVAC effect”), versus Earth albedo change due to a cool roof retrofit (“albedo effect”).

The Relationship between Radiative Forcing and GWP

Solar energy arrives at Earth primarily as shortwave radiation (light). Some of the shortwave radiation is reflected back into space by the atmosphere, clouds and Earth’s surface; the rest is absorbed and re-emitted as longwave (infrared) radiation. Scientists typically report the energy arriving and departing from Earth, whether shortwave or longwave, as a global total in watts (W) divided by the Earth’s total surface area in square meters (m^2). For scale, the solar energy arriving at the top of the atmosphere provides an average energy flux of about 342 W/m^2.

When the Earth’s climate is stable, the total radiative energy leaving the planet is equal to the solar energy arriving at the planet.[1] Global warming is destabilization of this balance: the radiation leaving the planet is less than the amount of solar energy arriving. The surface of the planet will warm until the amount of departing energy once again equals the amount arriving.

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[1] There is a small quantity of geothermal energy (about 0.087 W/m^2 – see Henry N. Pollack, Suzanne J. Hurter, and Jeffrey R. Johnson, “Heat Flow from the Earth’s Interior: Analysis of the Global Data Set,” Reviews of Geophysics 31, no. 3 (1993): 267) making this balance more complex. Because the quantity of geothermal energy is very small, and because it is not anthropogenically affected, it does not impact the heuristic description of the radiative energy budget being given here.

This shortage of energy leaving the planet is the **radiative forcing** and is also measured in W/m^2. The Intergovernmental Panel on Climate Change (IPCC) quantifies the driving force behind global warming by assuming zero radiative forcing as of 1750, and computing radiative forcing from known changes to the atmosphere and surface since that date. For scale, the current radiative forcing is approximately 3.0 W/m^2.

GHGs increase radiative forcing by absorbing longwave radiation departing from the surface or lower atmosphere. The longwave radiation would otherwise have departed to space, but instead the GHGs reradiate a portion back toward the surface.

Surface albedo enhancement decreases radiative forcing by avoiding absorption of arriving shortwave radiation. Instead of being converted to longwave radiation at the surface, the arriving radiation is simply reflected into space.

The reference unit used in GHG measurement and management is the radiative forcing due to a one kilogram (kg) pulse of carbon dioxide (CO_2) added to the atmosphere, integrated over a period of 100 years following the pulse.[2] The **global warming potential** (GWP) of any other GHG is the radiative forcing integrated over 100 years per kilogram of the GHG, divided by the kgCO_2 reference unit. The 100-year **time horizon** used for computing GWP is a relatively arbitrary choice. Changing the time horizon affects the relative weights of GHGs strongly, because some have atmospheric half-lives considerably shorter than 100 years, while CO_2 follows a complex decay function that unfolds over thousands of years.[3] The appropriateness of both the 100-year time horizon and the GWP itself have been, and will continue to be, under debate.[4]

Provisional Definition of Albedo Forcing Potential (AFP$_{.01}$)

Since albedo change also alters radiative forcing, one can compute the global warming potential of an albedo change analogously to the GWP of a GHG. Doing so requires choosing a unit of albedo change that will be compared with the 1 kgCO_2 pulse; for the purposes of this memo I will provisionally define **albedo forcing potential** (AFP$_{.01}$) as the radiative forcing due to a 0.01 albedo decrease (darkening) over a surface area of 1 m^2, divided by the radiative forcing due to a 1 kg pulse of CO_2., integrated over a period of 100 years. More intuitively: **AFP$_{.01}$ is the one-time CO_2 emission causing the same change to radiative forcing as one square meter darkened by .01**.

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[2] Though IPCC defines GWP according to a 1 kg pulse, professionals in GHG measurement and management typically work in units of metric tons rather than kilograms. From the point of view of the global atmosphere these are both infinitesimal units and the physics in the atmosphere will be identical per mass unit.

[3] David Archer et al., "Atmospheric Lifetime of Fossil Fuel Carbon Dioxide," *Annual Review of Earth and Planetary Sciences* 37, no. 1 (May 2009): 117–34, https://doi.org/10.1146/annurev.earth.031208.100206.

[4] See, e.g. Keith P. Shine et al., "Alternatives to the Global Warming Potential for Comparing Climate Impacts of Emissions of Greenhouse Gases," *Climatic Change* 68, no. 3 (February 2005): 281–302, https://doi.org/10.1007/s10584-005-1146-9.

A policy-appropriate definition of $AFP_{.01}$ will require more precision relating to time and location, but this provisional definition is sufficient to consider the approximate, potential contribution albedo management can make to global warming mitigation. For example, imagine a new albedo management policy prescribes $AFP_{.01} = 0.25\ kgCO_2/m^2$. A hypothetical albedo project replaces an existing, 160 m^2 residential roof having albedo 0.20 with a cool roof having albedo 0.50, producing 30 units of .01 albedo change. The project's equivalent greenhouse gas reduction is $30 \times 160\ m^2 \times 0.25\ kgCO_2/m^2 = 1{,}200\ kgCO_2e$, or 1.2 metric tons of CO_2-equivalent.

How $AFP_{.01}$ Relates to Time

The relationship between a metric like $AFP_{.01}$ and time is complex.[5] Understanding and accounting for this complex relationship to time will be the principal challenge of creating policy that makes albedo increases fungible with GHG reductions.[6] There are three domains of time-sensitivity.

1. Drift in Project Albedo

Over the course of a project's lifetime, the albedo may change. In the case of cool roofs, the primary such change is due to weathering. Over time, degradation in the roofing material and accumulation of dirt and detritus can both decrease the albedo. Maintenance and cleaning ameliorate this effect, but of course the timing and quality of the maintenance and cleaning events induce their own, poorly predictable variance over time.

2. Project Duration

If albedo at a project site returns to its pre-project value, there is an instantaneous loss of the project's radiative forcing change to the climate system. In contrast, once a GHG emission has been avoided, the climate impact of the avoided emission persists through the 100-year time horizon, to whatever degree the unavoided GHG emission would have persisted through the 100-year time horizon.

The $AFP_{.01}$ metric is only accurate to the extent that the albedo project lasts as long as the time horizon. Possible remedies for this limitation include:

- Shorten the GWP time horizon to a period commensurate with typical albedo project length;

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[5] Ryan M. Bright et al., "Carbon-Equivalent Metrics for Albedo Changes in Land Management Contexts: Relevance of the Time Dimension," *Ecological Applications* 26, no. 6 (September 2016): 1868–80, https://doi.org/10.1890/15-1597.1.

[6] Fungibility is not necessarily a policy goal. Non-interactive incentive programs for GHG reductions and albedo increases, respectively, can still meet sophisticated climate management goals.

- Compute project-specific $AFP_{.01}$ values, that mathematically account for variable albedo within the time horizon;[7]
- Use a standardized $AFP_{.01}$ value, but prorate project climate credits according to the fraction of the time horizon covered; or
- Deploy policy changes that promise persistence of the albedo change throughout the time horizon.

3. Decay of the CO_2 Reference Pulse

The 1 kg CO_2 reference pulse decays substantially during the 100-year time horizon. This means that the reference radiative forcing is not a constant, so computation of $AFP_{.01}$ can and should relate to the difference between the albedo project and the reference pulse's radiative forcing over time. This particular time effect does not need policy attention *per se*, but understanding it is critical to developing a physically meaningful mathematical formulation for $AFP_{.01}$.

How $AFP_{.01}$ Relates to Location

The impact of albedo to radiative forcing is different, in differing local circumstances. Each of the following can and does have an effect:[8]

- **Latitude**. Albedo changes at very high latitudes will have a smaller effect per unit surface area than at lower latitudes.
- **Cloud cover**. Albedo changes in sunnier climates will have a greater relative effect.
- **Aerosols/pollution**. Any substance that absorbs shortwave radiation between the Earth's surface and the top of the atmosphere, reduces the climate impact of albedo changes.
- **Shading**. Trees, hillsides, neighboring buildings, or other structures that cast shade on the roof will reduce the impact of albedo change.
- **Snow cover**. Climates that experience substantial snow cover each year will produce smaller effects from albedo changes in the built environment.

Recognizing these local effects requires either computing $AFP_{.01}$ on a project-specific basis, or establishing project correction factors that adjust CO_2-equivalents computed with a generalized $AFP_{.01}$. Hybrid solutions are possible, for example a set of semi-generalized $AFP_{.01}$ values might be established for multiple latitudes, and the remaining location-specific parameters handled as correction factors.

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[7] This remedy can address the first type of time-dependence (albedo drift) as well.

[8] Urban albedo changes strongly influence the local, urban heat island effect. However, changes to the urban heat island effect do not in turn impact $AFP_{.01}$, because urban air temperature has a negligible impact on reflected shortwave radiation. Hence, urban heat island reduction should be treated as a co-benefit of albedo management policy, but ignored in computation of $AFP_{.01}$.

Values of AFP$_{.01}$ in Literature

Values from five studies that attempt to cast the global-average effects of albedo change in the built environment into CO_2 equivalents (CO_2e) are summarized in Figure 1. These five studies all provide independently computed values (or proxies) for AFP$_{.01}$.

study	AFP$_{.01}$ *kgCO$_2$e/m^2*
Akbari, Menon & Rosenfeld 2009	2.55
Akbari, Matthews & Seto 2012	
min	6.50
max	7.50
Campra et al 2008	4.3
Menon et al 2010	3.26
Muñoz & Campra 2010	
min	2.44
max	5.07
per-study average	**4.17**

Figure 1 – Compiled values of AFP$_{.01}$ reported in five published papers

The two studies lead-authored by Akbari,[9,10] and Menon *et al*,[11] report AFP$_{.01}$ directly following the same definition used in this memo. Campra *et al*[12] is given as interpreted and cited by Akbari, Matthews & Seto 2012. Values from Muñoz & Campra[13] were computed by HLLC using only parameters available in the published paper.[14] On average, the five studies estimate a nominal AFP$_{.01}$ of 4.17 kgCO_2e/m^2 when integrating over a 100-year time horizon. Muñoz & Campra were unique in offering an explicit discussion of uncertainty in this value, and

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[9] Hashem Akbari, Surabi Menon, and Arthur Rosenfeld, "Global Cooling: Increasing World-Wide Urban Albedos to Offset CO2," *Climatic Change* 94, no. 3–4 (June 2009): 275–86, https://doi.org/10.1007/s10584-008-9515-9.

[10] Hashem Akbari, H Damon Matthews, and Donny Seto, "The Long-Term Effect of Increasing the Albedo of Urban Areas," *Environmental Research Letters* 7, no. 2 (June 1, 2012): 024004, https://doi.org/10.1088/1748-9326/7/2/024004.

[11] Surabi Menon et al., "Radiative Forcing and Temperature Response to Changes in Urban Albedos and Associated CO_2 Offsets," *Environmental Research Letters* 5, no. 1 (January 2010): 014005, https://doi.org/10.1088/1748-9326/5/1/014005.

[12] Pablo Campra et al., "Surface Temperature Cooling Trends and Negative Radiative Forcing Due to Land Use Change toward Greenhouse Farming in Southeastern Spain," *Journal of Geophysical Research* 113, no. D18 (September 23, 2008), https://doi.org/10.1029/2008JD009912.

[13] Ivan Muñoz, Pablo Campra, and Amadeo R. Fernández-Alba, "Including CO2-Emission Equivalence of Changes in Land Surface Albedo in Life Cycle Assessment. Methodology and Case Study on Greenhouse Agriculture," *The International Journal of Life Cycle Assessment* 15, no. 7 (August 2010): 672–81, https://doi.org/10.1007/s11367-010-0202-5.

[14] See HLLC workbook number CR-002(b).

concluded that an error of approximately ±35% was appropriate. Applying Muñoz & Campra's error estimate to the per-study average results in a range of **2.71** to **5.63 kgCO_2e/m^2**.

In addition to these studies suggesting a computable relationship between radiative forcing from albedo and from greenhouse gases,[15] there are many peer-reviewed case studies in the literature that quantify climate impacts of albedo change in land use or the built environment. Many of these case studies report a scalar result in CO_2e or similar units, but the observed albedo change is almost always spatially distributed and study authors rarely report its area-weighted average. Hence, the implied ratio between CO_2e and albedo change cannot be computed from most of these study reports. I did find three exceptions (Figure 2).

study	land use change type	location	temporal treatment	*in-situ* AFP$_{.01}$ kgCO_2e/m^2
Cotana et al 2014	building surface brightening	Tunisia	static	1.40 - 2.10
VanCuren 2012	cool roofs	California	static	0.99 - 1.52
Xu et al 2020	pavement brightening	U.S. (various)	dynamic	0.81 - 1.60

Figure 2 – Values of AFP$_{.01}$ implied by three case studies.

Cotana *et al* 2014 evaluates a small-scale, urban project on one industrial site, demonstrating the practical value of AFP$_{.01}$.[16] VanCuren 2012 was authored under the auspices of the California Air Resources Board and is a particularly relevant case study as it considers cool roofs in California.[17] The range of VanCuren's results shown in Figure 2 cover the lowest- to highest-insolation California climate zones, Zone 3 to Zone 15. The author's definition of AFP$_{.01}$ scales against ambient (atmospheric) CO_2 rather than emitted CO_2, so the range of results shown are lower than those relating to emitted CO_2.[18] Finally, in Xu *et al*'s 2020 study of pavement albedo, the authors computed AFP$_{.01}$ integrated over a 50-year time horizon for various United States cities, with results ranging from 0.8 to 1.6 kgCO_2e/m^2.[19] The authors point out that their relatively low-ranging results are likely due to the significant shading of urban pavement. Since

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[15] The computable relationship between radiative forcing from albedo and from greenhouse gases is not a perfect predictor of the relationship between *global warming* from albedo and from greenhouse gases. The change to radiative forcing due to albedo may induce somewhat more or less global warming than an identical change to radiative forcing due to greenhouse gases. The change to radiative forcing from albedo is local, while greenhouse gases are globally mixed, which produces different results in a global circulation model. Climate sensitivity can and should be considered among the parameters that would determine a policy-relevant definition of AFP$_{.01}$.

[16] Franco Cotana et al., "Albedo Control as an Effective Strategy to Tackle Global Warming: A Case Study," *Applied Energy* 130 (October 2014): 641–47, https://doi.org/10.1016/j.apenergy.2014.02.065.

[17] Richard VanCuren, "The Radiative Forcing Benefits of 'Cool Roof' Construction in California: Quantifying the Climate Impacts of Building Albedo Modification," *Climatic Change* 112, no. 3–4 (June 2012): 1071–83, https://doi.org/10.1007/s10584-011-0250-2.

[18] Virtually all GHG regulation counts emitted GHGs, so if a goal of the AFP$_{.01}$ definition is fungibility in existing regulatory schemas, it should relate to emitted GHGs.

[19] Xin Xu et al., "Quantifying Location-Specific Impacts of Pavement Albedo on Radiative Forcing Using an Analytical Approach," *Environmental Science & Technology* 54, no. 4 (February 18, 2020): 2411–21, https://doi.org/10.1021/acs.est.9b04556.

roofs are less affected by shading, these results can be considered a lower bound on the values that might be computed using a locally sensitive formulation for AFP$_{.01}$ that is geared to roofs.

Example: Comparing the Albedo Effect to the HVAC Effect

Both to provide an example application of AFP$_{.01}$, and to appreciate the scale of the albedo effect, I compare it to the HVAC effect computed in a landmark simulation of cool roofs. Lawrence Berkeley National Laboratory (LBNL) published *Solar-Reflective "Cool" Walls: Benefits, Technologies, and Implementation* in 2019, including thousands of simulations of several protype buildings. One of these prototypes is a 2,400 ft^2, two-story, single-family residence with an 18.4° slope roof.[20] Though the study's published materials focus on cool walls, the modeling regime was comprehensive and includes control of both roof and wall albedos. The prototype home roof has albedo 0.10 in the base case.

The authors model target, cool roof albedos of 0.25, 0.40, and 0.60. Here I draw results from the intermediate target of 0.40 which, relative to the baseline albedo 0.10, represents 30 of the 0.01 albedo change units underlying the AFP$_{.01}$ metric.

The authors offer results for three different home vintages, in all sixteen of the California Energy Commission climate zones. Figure 3a shows the magnitude of the HVAC effect for all three vintages in low-insolation Climate Zone 3, represented by the city of Oakland, and for high-insolation Climate Zone 15, represented by the city of Imperial.

	reduction, kgCO$_2$e/m^2-yr	
building vintage	Zone 3 Oakland, CA	Zone 15 Imperial, CA
new	0.256	0.406
older	0.343	0.886
oldest	0.637	1.595

Figure 3a – HVAC Effect as reported by Levinson *et al* 2019, for a change in roof albedo from 0.10 to 0.40. GHG reduction intensities in units of kgCO$_2$e/m^2-yr represent the reduction in direct and indirect GHG emissions induced by energy demand reduction, per unit roof area. Building vintage "older" means, approximately, 1980's; building vintage "oldest" means, approximately, pre-1978.

The values in Figure 3a represent 30 units of .01 albedo change, so to make the values numerically consistent with values for AFP$_{.01}$ they should be divided by 30. The values only represent avoided GHGs for a single year of operation. Without attempting a sophisticated treatment of time for this order-of-magnitude comparison, we can simply multiply the single-year performance by 25 years to represent the cumulative benefit over the lifetime of a roof.

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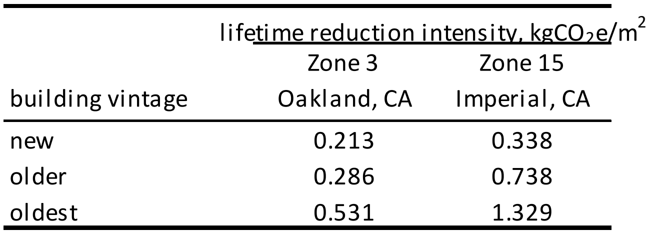
[20] Ronnen Levinson et al., "Solar-Reflective 'Cool' Walls: Benefits, Technologies, and Implementation," April 1, 2019, http://www.osti.gov/servlets/purl/1615340/.

Figure 3b repeats Figure 3a but with all values multiplied by 25/30 to allow comparison to AFP$_{.01}$.



	lifetime reduction intensity, kgCO$_2$e/m^2	
	Zone 3	Zone 15
building vintage	Oakland, CA	Imperial, CA
new	0.213	0.338
older	0.286	0.738
oldest	0.531	1.329

Figure 3b – HVAC Effect for one .01 unit of albedo change, over the 25-year lifetime of a roof. Adapted from Levinson *et al* 2019.

The computed HVAC effect in California appears to range from **0.213** to **1.33 kgCO$_2$e/m^2**. The albedo effect described in literature, AFP$_{.01}$ = 2.71 kgCO$_2$e/m^2 to 5.63 kgCO$_2$e/m^2, is larger than the HVAC effect. If the AFP$_{.01}$ values are reduced by a factor of 25/100 to account for a 25-year roof life relative to the 100-year GWP horizon,[21] the reduced range AFP$_{.01}$ = 0.68 kgCO$_2$e/m^2 to 1.41 kgCO$_2$e/m^2 is on par with the HVAC effect for the oldest building vintage but is still substantially larger than the HVAC effect in new buildings across climate zones.

Conclusion

This simple comparison demonstrates that for cool roof retrofits, the albedo effect on radiative forcing can exceed the HVAC effect. Albedo management is a powerful tool for global warming mitigation, and should be considered with equal weight to greenhouse gas management. Today's global warming mitigation policy tools have been built only around greenhouse gas management, so making albedo project metrics fungible with greenhouse gas metrics would ease entry of albedo projects into the current paradigm. A well-considered definition of AFP$_{.01}$ is the key to enabling that.

Respectfully submitted,

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[21] Representing a relatively simplistic approach to correcting for project duration. A more sophisticated approach might prorate AFP$_{.01}$ more or less strongly, depending on the methodology.