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Introduction

Increasing worldwide surface albedo, or reflectivity, starting in urban areas, can help fight climate change by offsetting radiative forcing[1] from carbon dioxide ("CO_2") and other climate forcing gases and aerosols. This can delay impacts of dangerous anthropogenic interference with the climate system and complement strategies to make long-term reductions in CO_2 emissions. Installation of high-albedo "cool roofs" across urban areas could also reduce future CO_2 emissions from fossil fuel derived electricity used for air conditioning. Several U.S. states have policies supporting cool roof installation to reduce energy usage, improve air quality, and alleviate the urban heat island effect. The U.S. Department of Energy has announced a series of initiatives to improve and broaden implementation of cool roof technologies. Such policies are supported by a number of scientific studies that demonstrate the benefits of albedo enhancement both to cities and to the global climate.

Climate Tipping Points and Dangerous Anthropogenic Interference

The goal of climate change policy is to avoid "dangerous anthropogenic interference with the climate system," according to the United Nations Framework Convention on Climate Change ("UNFCCC").[2] As Parties to the UNFCCC continue negotiating the elements of a fair and effective treaty, emissions of greenhouse gases and aerosols continue to increase. The observed global temperature, which is estimated to have risen about 0.76°C since pre-industrial times, also increases. Temperature thresholds for tipping points, such as the collapse of the Greenland Ice Sheet and the dieback of the Amazon Rainforest, could be passed with an increase of 1-4ºC over pre-industrial levels. According to one study, the "committed" level of warming from emissions through 2005 is 2.4°C (1.4–4.3°C). This 2.4°C is comprised of the observed warming plus an additional 1.6°C that is temporarily lagged in the oceans and masked by cooling sulfate aerosols that are now being reduced for public health reasons.[3] This 2.4°C and associated climate change impacts put the climate system within the zone of "dangerous anthropogenic interference" already.[4]

International climate policy has focused primarily on long-term reductions of CO_2, the principle greenhouse gas responsible for 50% of radiative forcing since 1750.[5] However, due to the profoundly long atmospheric life of CO_2—centuries to millennia[6]—and the expected contribution from committed warming, "climate change that takes place due to increases in carbon dioxide concentrations is largely irreversible for 1,000 years after emissions stop."[7] To delay warming while pursuing aggressive CO_2 mitigation, climate policy must include mitigation of the 50% of radiative forcing from non-CO_2 gases and aerosols, as well as carbon negative strategies to draw down excess CO_2 already in the atmosphere, starting with bio-sequestration through biochar.[8] The main non-CO_2 forcers are black carbon, hydrofluorocarbons, methane, and tropospheric (ground level) ozone. These gases and aerosols have atmospheric lifetimes of days to a decade and a half, so reducing them can produce a fast response in the climate system. Like these other fast action strategies, increasing worldwide urban albedos could help delay warming and associated impacts.

Albedo Enhancement Can Offset Radiative Forcing From CO_2

Albedo refers to the percentage of solar radiation reflected by a surface or an object measured on a scale from zero to one, with one being the most reflective.[9] Surfaces with high albedos, such as snow-covered land, reflect high percentages of shortwave solar radiation preventing conversion to longwave infrared radiation that heats both the surface and the atmosphere. Surfaces with low albedos include the ocean and land with vegetative cover, so deforestation and land use changes since pre-industrial times have increased albedo and actually produced a negative radiative forcing of $-0.2W\ m^{-2}$, with uncertainty of $\pm\ 0.2W\ m^{-2}$.[10] This albedo enhancement is providing a small offset, compared to the 1.6 $W\ m^{-2}$ forcing from CO_2[11] and the comparable forcing from non-CO_2 warming agents. Recent studies demonstrate that enhancing urban albedo can produce additional negative radiative forcing without the downside of environmental damage.[12]

A recent study by researchers at the Lawrence Berkeley National Laboratory ("LBNL") concludes that increases in

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urban surface albedos in temperate and tropical regions by 0.1 could produce a one-time offset for emitted CO_2 of approximately 57 gigatons ("Gt") CO_2.[13] For comparison, it is estimated that energy-related CO_2 emissions were ~28.8 Gt in 2007 and total greenhouse gas emissions were ~42.4 Gt CO_2-equivalent in 2005.[14] The LBNL researchers use a detailed land surface model developed by NASA to perform simulations of boreal summers (June to August) over a twelve-year period. Based on simulation-generated data, they calculate that the potential offsets from increasing roof albedos by 0.25 and pavement albedos by 0.15 would be ~31 Gt CO_2 from roofs and ~26 Gt CO_2 from pavements for a total of 57 Gt CO_2.[15]

The LBNL study is a follow up to a paper published in 2009 by the same research team using many of the same variables,[16] the results of which were questioned by a review that concluded offset potential had been overestimated.[17] However, at least part of the criticism of the 2009 paper—centering on the estimate of the percentage of global land area occupied by urban surfaces[18]—was addressed by the 2010 study, which uses satellite data rather than global estimates.[19]

Albedo Enhancement Can Save Energy and Improve Air Quality

Simply removing radiation from the climate system by increasing surface albedo does not, of course, fix the underlying problem of accumulating emissions of CO_2 and other climate warming gases and aerosols.[20] However, cool roofs, made from light-colored, highly reflective materials, indirectly decrease CO_2 emissions by keeping buildings cool, reducing electricity needs for air conditioning.[21] Cooler buildings and pavements can also reduce summertime temperatures, improve air quality, and help to alleviate other problems associated with the urban heat island effect.[22] On average, increased rooftop albedo was found to decrease building cooling costs more than 20% for a rooftop albedo increase of 40-50%, according to the 2009 LBNL study.[23] The LBNL study also found that in the United States, combined energy and air quality savings from urban albedo enhancement could exceed $2 billion per year.[24]

An independent study of rooftop albedo enhancement based on models finds that average daily maximum urban temperature decreased by 0.6ºC and daily minimum temperature decreased by 0.3ºC, suggesting increasing albedo is an effective method of diminishing urban heat island effect.[25] Although the authors caution that energy savings from reduced air conditioning should be weighed against increased heating costs in winter where applicable, they also note that as air conditioning becomes more common globally, the role of cool roofs may expand.[26]

Cool Roofs to Enhance Urban Albedo in the United States

On July 19, 2010, U.S. Secretary of Energy Steven Chu announced that initiatives to install cool roofs and promote albedo enhancement are underway at the Department of Energy ("DOE").[27] The DOE plans to construct cool roofs where cost effective on its own properties and is advising other federal agencies to undertake similar projects.[28] To help facilitate such projects, the DOE published the manual Guidelines for Selecting Cool Roofs, which contains technical information for both agencies and commercial builders.[29]

In 2005, California introduced cool roofs as an option for satisfying the state's strict efficiency requirements, and, in January 2010, cool roofs became mandatory for certain structures.[30] Other states and cities have enacted similar regulations, including requiring cool roofs under some circumstances.[31] The federal government now intends to play a leading role, installing cool roofs on DOE buildings across the country, including its headquarters in Washington, DC.[32]

Geoengineering with Large-Scale Albedo Enhancement

The offset potential of surface albedo enhancement has inspired proposals for more expansive implementation through geoengineering, which is defined as efforts to counteract the greenhouse effect by directly managing Earth's energy budget.[33] Geoengineering typically entails large-scale manipulation of the environment; therefore, urban albedo enhancement and other strategies that effect relatively small changes in radiative forcing are sometimes referred to as "soft geoengineering" or "geoengineering light."[34] One type of albedo modification-based geoengineering scheme entails covering arid regions or low albedo deserts with heat reflecting sheets,[35] while another focuses on switching to natural or bioengineered grasses, shrubs, and crops that are lighter in color and more reflective.[36]

Unlike installations of cool roofs and pavements, these geoengineering schemes do not provide benefits of energy efficiency or urban heat island alleviation. Moreover, large-scale surface albedo enhancement may cause negative effects including extreme regional cooling and interference with local weather.[37] However, these effects can be monitored as desert albedo enhancement is scaled up, and the albedo can be returned to its original level if impacts are too severe, unlike the potential impacts of other types of geoengineering schemes, for example, putting mirrors into orbit in space.

Conclusion

Enhancing urban albedo is an easy and effective way to reduce electricity needs and diminish urban heat island effect, and it can be implemented quickly, as existing roads and roofs are replaced and new ones constructed. Several states and the U.S. government have policies including incentives to encourage installation of cool roofs for efficiency purposes. Increasing albedos of urban roofs and pavements globally would also produce climate mitigation in the form of an offset to radiative forcing from CO_2. Together with other non-CO_2 fast-action mitigation strategies, urban albedo enhancement can help delay peak warming and associated impacts while aggressive cuts are being made to long-term CO_2 emissions. Increasing urban albedo is the "light" counterpart to large-scale surface albedo modification, which, among geoengineering options, is preferred to other schemes that carry significant risk of unforeseen and unmanageable side effects.

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1 Piers Forster et al., Intergovernmental Panel on Climate Change ("IPCC"), *Changes in Atmospheric Constituents and in Radiative Forcing*, *in* Climate Change 2007: The Physical Science Basis 136 (Susan Solomon et al. eds., 2007), http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf (explaining that radiative forcing refers to the influence of factors on the balance between the solar radiation entering and the infared radiation exiting the atmosphere).

2 United Nations Framework Convention on Climate Change art. 2, May 9, 1992, 1771 U.N.T.S. 107, 165.

3 Veerabhadran Ramanathan & Yan Feng, *On Avoiding Dangerous Anthropogenic Interference with the Climate System: Formidable Challenges Ahead*, 105 Proc. Nat'l Acad. Sci. USA 14245, 14247 (2008) ("About 8% of the committed warming (0.2°C) is compensated by increases in the surface albedo because of land-use changes; ~20% (0.5°C) is delayed by the thermal inertia of the oceans and it is only the balance of ~25%, i.e., 0.6°C, that should by now have manifested as observed warming. This algebraic exercise demonstrates that the observed surface warming of 0.76°C (since the latter half of 1800s) is not inconsistent with the committed warming of 2.4°C. The fundamental deduction (subject to the assumption of IPCC climate sensitivity) is that if we get rid of the ABCs today the Earth could warm another 1.6°C (which includes the delayed warming caused by ocean thermal inertia) unless we act now to reduce GHG concentrations.").

4 James Hansen et al., *Target Atmospheric CO_2: Where Should Humanity Aim?* 2 Open Atmospheric Sci. J. 217, 217 (2008) (recounting that although the United Nations Framework Convention on Climate Change aims to stabilize levels of greenhouse gases in the atmosphere to prevent "dangerous anthropogenic interference with the climate system . . . the present global mean CO2, 385 ppm, is already in the dangerous zone").

5 Forster et al., *supra* note 1, at 136.

6 Gerald A. Meehl et al., IPCC, *Global Climate Projections*, *in* Climate Change 2007: The Physical Science Basis 824 (S. Solomon et al. eds., 2007), http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter10.pdf.

7 Susan Solomon et al., *Irreversible Climate Change Due to Carbon Dioxide Emissions*, 106 Proc. Nat'l Acad. USA 1704, 1704 (2009), http://www.pnas.org/content/early/2009/01/28/0812721106.full.pdf.

8 *See* Mario Molina, Durwood Zaelke, K. Madhava Sarma, Stephen O. Andersen, Veerabhadran Ramanathan & Donald Kaniaru, *Reducing Abrupt Climate Change Risk Using the Montreal Protocol and Other Regulatory Actions to Complement Cuts in CO_2 Emissions*, 106 Proc. Nat'l Acad. Sci. USA 20616 (2009).

9 IPCC, *Glossary*, *in* Climate Change 2007: The Physical Science Basis 941 (Alphonsus P. M. Baede ed., 2007), http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-annexes.pdf.

10 Forster et al., *supra* note 1, at 132 (explaining that land cover changes, largely due to net deforestation, have increased the surface albedo, producing radiative forcing of –0.2 [±0.2]W m^{-2}).

11 Surabi Menon, et al., *Radiative Forcing and Temperature Response to Changes in Urban Albedos and Associated CO_2 Offsets*, 5 Envtl. Res. Letters 014005 (2010) ("The global radiative forcing associated with land use and land cover change from pre-industrial times to present day due to land albedo modifications is about -0.2 ± 0.2 Wm^{-2} . . . . This value is small but of opposite sign compared to the 1.6 Wm^{-2} forcing from CO_2." (*citing* Forster et al., *supra* note 1, at 136)).

12 *Id*. ("Over 60% of typical US urban surfaces are pavements and roofs . . . and roofs and paved surfaces constitute about 20-25% to 29-44%, respectively of typical metropolitan US urban surfaces . . . . Thus the potential modification to albedos of urban surfaces can have a strong effect on radiative forcing and it becomes useful to quantify this effect since it can to some extent mitigate or delay some of the consequences of warming from CO_2 emissions." (*citing* Hashem Akbari et al., *Analyzing the Land Cover of an Urban Environment Using High-resolution Orthophotos*, 63 Landscape & Urb. Plan. 1 (2003) and Leanna Shea Rose et al., Characterizing the Fabric of the Urban Environment: A Case Study of Greater Houston, Texas (2003)).

13 *Id*.

14 International Energy Agency, World Energy Outlook 2009 168, n. 1 (2009) ("Carbon dioxide equivalent (CO_2-eq) is a measure used to compare and combine the emissions from various greenhouse gases, and is calculated according to global-warming potential of each gas."); *id*. at 44 ("The Reference Scenario sees a continued rapid rise in energy-related CO_2 emissions through to 2030, resulting from increased global demand for fossil energy. Having already increased from 20.9 [gigatonnes ("Gt")] in 1990 to 28.8 Gt in 2007, energy-related CO_2 emissions are projected to reach 34.5 Gt in 2020 and 40.2 Gt in 2030—an average rate of growth of 1.5% per year over the full projection period (Figure 2.1)."); *id*. at 169 ("Total emissions of greenhouse gases, across all sectors, were 42.4 gigatonnes (Gt) of CO_2-eq in 2005 (Figure 4.1).").

15 Menon et al., *supra* note 11 ("Based on the radiative flux changes we obtained from the CLSM we now examine the CO_2 offsets that may be expected. We use RF01A to define the radiative forcing obtained for a 0.01 change in albedo . . . . The atmospheric CO_2 equivalence for a 0.01 increase in urban albedo is then obtained from the ratio of RF01A (1.63W m^{-2}) to the radiative change per tonne of atmospheric CO_2. This value is -1.79 kg CO_2 m^{-2} urban area."); *id*. ("These averages represent all global land areas where data were available from the land surface model used and are for the boreal summer (June–July–August)."); *id*. ("If roof areas are 25% of urban areas (~3.8×10^{11} m^2) and paved areas are 35% of urban areas (~5.3×10^{11} m^2), we then estimate 31 and 26 Gt CO_2 offsets for cool roofs and pavements, respectively.").

16 Hashem Akbari et al., *Global Cooling: Increasing Worldwide Urban Albedos to Offset CO_2*, 94 Climatic Change 275, 284 (2009), http://www.energy.ca.gov/2008publications/CEC-999-2008-020/CEC-999-2008-020.PDF ("Using cool roofs and cool pavements in urban areas, on an average, can increase the albedo of urban areas by 0.1. We estimate that increasing the albedo of urban roofs and pavements [on a global scale] will induce a negative radiative forcing of 4.4×10^{-2} Wm^{-2} equivalent to offsetting 44 Gt of emitted CO_2.").

17 Timothy Lenton & Naomi Vaughan, *The Radiative Forcing Potential of Different Climate Geoengineering Options*, 9 Atmospheric Chemistry & Physics Discussions 5539, 5550 (2009), available at http://www.atmos-chem-phys.net/9/5539/2009/acp-9-5539-2009.pdf ("Assuming 1% of the land surface (1.5×1012 m2) is urban this has been estimated to induce a radiative forcing of −0.044Wm−2 . . . we estimate RF=−0.047Wm−2 (Table 1). However, satellite observations suggest the actual global urban area may be far less than assumed . . . at 2.6×1011 m2 . . . or 0.051% of the Earth's surface, which . . . would give RF=−0.0081Wm−2." (citing Akbari et al., supra note 16; Matthew C. Hansen et al., Global Land Cover Classification at 1km Spatial Resolution Using a Classification Tree Approach, 21 Int'l. J. Remote Sensing 1331 (2000); Thomas R. Loveland et al., Development of a Global Land Cover Characteristics Database and IGBP DISCover from 1 km AVHRR Data, 21 Int'l. J. Remote Sensing 1303 (2000)).

18 *Id*.

19 Menon et al., *supra* note 11.

20 Akbari et al., *supra* note 16, at 284.

21 Menon et al., *supra* note 11 (explaining that increasing albedo in turn increases the outgoing radiation and reduces heat and by extension the demand for energy for air conditioning; if that energy were supplied by fossil fuels, the increase in albedo would then reduce CO_2 emissions).

22 Akbari et al., *supra* note 16, at 275; Menon et al., *supra* note 11, at 279 (noting that reflective surfaces generally lead to cooler urban temperatures, which slow smog formation).

23 *Id*. at 275 ("[M]any studies have demonstrated reductions of more than 20% in cooling costs for buildings whose rooftop albedo has been increased from about 10-20% to about 60% (in the US, potential savings exceed 1 billion per year).").

24 *Id*. at 276.

25 Keith Oleson et al., *Effects of White Roofs on Urban Temperature in a Global Climate Model*, 37 Geophysical Res. Letters L03701 (2010) ("Here, the effects of globally installing white roofs are assessed using an urban canyon model coupled to a global climate model. Averaged over all urban areas, the annual mean heat island decreased by 33%. Urban daily maximum temperature decreased by 0.6ºC and daily minimum temperature by 0.3ºC.").

26 *Id.*

27 Press Release, U.S. Dep't of Energy (July 19, 2010), *available at* http://energy.gov/news/9225.htm.

28 *Id*.

29 U.S. Dep't of Energy, Guidelines for Selecting Cool Roofs (2010).

30 Cal. Code Regs. tit. 24 § 118 (2010).

31 *See*, *e.g*., Fla. Stat. § 553.9061 (2010).

32 Press Release, U.S. Dep't of Energy, *supra* note 27.

33 IPCC, *Glossary*, *in* Climate Change 2007: Mitigation of Climate Change 815 (Aviel Verbruggen ed., 2007) (defining geo-engineering as "[e]fforts to sta-

bilise the climate system by directly managing the energy balance of the earth, thereby overcoming the enhanced *greenhouse effect*.").

[34] *See*, *e.g.*, Samuel Thernstrom, *White Makes Right? Steven Chu's Helpful Idea*, THE AMERICAN, Jun. 5, 2009, *available at* http://www.american.com/archive/2009/june/white-makes-right-steven-chu2019s-helpful-idea/.

[35] *See*, *e.g.*, Takayuki Toyama & Alan Stainer, *Cosmic Heat Emission concept to 'stop' global warming*, 9 INT'L. J. GLOBAL ENVTL. ISSUES 151-153 (2009) (urging the use of the Heat Reflecting Sheet ("HRS") on Earth's surface); *see also* Alvia Gaskill, Summary of Meeting with US DOE to Discuss Geoengineering Options to Prevent Abrupt and Long-Term Climate Change, *available at* http://www.global-warming-geo-engineering.org/3/contents.html.

[36] Robert M. Hamwey, *Active Amplification of the Terrestrial Albedo to Mitigate Climate Change: An Exploratory Study,* 12 MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE 419, 435 (2007) (explaining that "[t]errestrial albedo amplification may stall climate change for about twenty-five years," during which humans can develop and implement long-term mitigation efforts such as low-emissions energy conversion); *see also* Andy Ridgwell et al., *Tackling Regional Climate Change By Leaf Albedo Bio-geoengineering*, 19 CURRENT BIOLOGY 1, 1 (2009) ("We quantify this by modifying the canopy albedo of vegetation in prescribed cropland areas in a global-climate model, and thereby estimate the near-term potential for bio-geoengineering to be a summertime cooling of more than 1°C throughout much of central North America and midlatitude Eurasia, equivalent to seasonally offsetting approximately one-fifth of regional warming due to doubling of atmospheric CO_2. Ultimately, genetic modification of plant leaf waxes or canopy structure could achieve greater temperature reductions, although better characterization of existing intraspecies variability is needed first.").

[37] Lenton & Vaughan, *supra* note 17, at 5556.