Equivalent CO2 Avoided by Reflective Roofs and Pavements in California

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Cool roofs are an accepted measure to reduce air conditioning load, thus to save electric bills and CO2 emissions. But in our companion paper[1] (attached) we introduce a new consideration of how cool roofs and pavements "offset" about ten times more CO2 than is avoided through reduced electric load. The new consideration is that white (or cool) surfaces increase the earth's reflectivity to sunlight (known as its "albedo") and hence cool the earth directly that is *equivalent* to reducing the greenhouse effect by removing CO2 from the atmosphere.

In this note, we show that an aggressive 15-year state-wide campaign for cool roofs and pavements is equivalent to reducing annual California emissions by 31MtCO2, or 18% of the AB32 goal for 2020 of 175 MtCO2/yr. This comparison is shown in Fig. 1. By a cool roofs/pavements campaign we are not suggesting white-washing of existing surfaces, but we are proposing that all new roofs on new construction and existing buildings be white (or at least use cool-coloured pigments). Cool pavements means that when asphalt is resurfaced the top layers of aggregate should be light colored, and where appropriate be finished with a white chip seal. We will discuss this further at the end of this note, under "Policy Implications" but first we give the reasoning behind the "albedo equivalence" of 31 MtCO2/year.

In the companion paper we relate the worldwide cooling by white roofs and cool pavements in all major tropical and temperate cities (about 1% of Earth's land area) and show that this is equivalent to offsetting emissions (over a period of say 15 years – the duration of the program) of CO2 by roughly 44 GtCO2, which is in turn equivalent to halting world-wide CO2 emissions over 1 year out of the next 15 years – or a significant reprieve from global warming. In this note we run through the same calculations for California.

Table 1 summarizes the results for California. The total California urban areas is estimated at 16,000 km^2 (4% of the total California area of 410,000 km^2). The estimated roof and paved surface areas are 4000 km^2 and 5600 km^2, respectively. In the attached paper, we estimate that increasing the solar reflectance of each m^2 of an urban surface by 0.01 produces a negative radiative forcing equivalent to offsetting CO2 emissions by 2.55 kg. Assuming an average increase of 0.25 and 0.15 in the solar reflectance of roofs and pavements, respectively, the equivalent CO2 offset is 470Mt CO2.

Most roofs are replaced every 10 to 25 years (residential roofs about 20-30 years, non-residential roofs about 10-20 years). Most paved surfaces are resurfaced about every 10 years. Here we estimate that, on the average, all urban surfaces can be changed to cool surfaces in 15 years. Hence, the annual Mt equivalent emission offset is about 31 Mt CO2/year. For comparison, Table 1 also lists the total savings from AB32 from 2010 to 2020 and the current annual CO2 emissions in California.

In addition to cooling the Earth, cool roofs also save air-conditioning (AC) electricity use. In California, we estimate that about 1/3 of residential and 2/3 of non-residential buildings are air conditioned. Assuming a modest average annual air-conditioning savings of about 3 kWh/m^2 of roof area, the annual AC savings in California is estimated at 6 BkWh. The annual CO2 emission reduction is estimated at 3 Mt (see Table 2). Although this 3 MtCO2/year has a short pay-back time and is an attractive measure for AB 32 early action, we note that it is only 1/10 of the albedo-equivalence of 31 MtCO2/year.

In Figure 1 we compare the potential of equivalent and actual CO2 savings from installing cool roofs and cool paved surfaces to that of the AB32. The AB32 target is to reduce the CO2 emissions by 175 Mt/year by 2020. If we assume a linear progress from 2010 to 2020 for implementation of the AB32 measures, the total CO2 savings during this period is 875 Mt. Assuming an average of 31 MtCO2-equivalent savings per year, the cool urban surfaces will produce an additional equivalent

[1] Akbari, Menon, and Rosenfeld, "Global Cooling: Increasing World-wide Urban Albedos to Offset CO2," submitted for publication, 21 Dec. 2007.

savings of 310 Mt during the same 10 years and will continue at the same annual rate of 31 Mt until 2025. After all the target urban surfaces are made reflective, this equivalent savings drops to zero in 2026. Only the cool-roofs AC savings, 3 MtCO2/year, will continue after 2026.

Policy Implications

Starting in 2005, California's Title 24 new building energy efficiency standard, called for "flat" roofs (technically "low sloped" – but invisible from the street) to be white. Sloped roofs, however, are more difficult because they are an important architectural element of a home. In "hot" states like Florida or Arizona, white roofs are stylish, but in California 80% of new homes are built with terra cotta coloured, hot, tiles, and re-roofs use dark, hot, shingles. Title 24 (2008) calls for these to be cooler by using the new "cool but colored" pigments and technology, but the solar reflectance threshold is modest (less than Energy Star), many of our 16 climate zones are excluded, and we fear that there will be very lax enforcement for the case of re-roofs. Fortunately the California investor-owned utilities (who administer $750 M/year of public-goods-funded energy efficiency programs) give rebates of up to $0.20/ft^2 to residential customers to help beat the standards and transform the market.

The issue of cool *pavements* remains without a sponsor – there is not even a list of available aggregates with information of solar reflectance, quarry location, color and price.

We conclude that the present modest program for cool roof only might provide the equivalent of 5-10 MtCO2/year by 2020, but to reach the goal of 31 MtCO2/year, a much higher priority is called for.

Acknowledgements

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California Table 1: CO2 equivalence of increasing the albedo of roofs and paved surfaces in all California urban areas.

Row	Item	Value
1.	Area of California	$410x10^9$ m^2
2.	Estimated California dense urban areas (about 4%)	$16x10^9$ m^2
3.	Roof area (25% of urban area) [a]	$4x10^9$ m^2
4.	Paved surface area (35% of urban area)	$5.6x10^9$ m^2
5.	Potential emitted CO2 equivalent reduction of cool roofs [Row 3 x Row 6a Table 4 of the attached paper]	260 Mt CO2
6.	Potential emitted CO2 equivalent reduction of cool pavements [Row 4 x Row 8a Table 4 of the attached paper]	210 Mt CO2
7.	Total potential emitted CO2 equivalent reduction of cool roofs and cool pavements [Row 5 + Row 6] [one-time only, not annual]	470 Mt CO2
8.	Time to resurfaces all roofs and pavements	15 years
9.	Annual CO2 equivalent emission reduction for cool roofs and cool pavements [Row 7 / Row 9]	31 Mt CO2/yr
10.	AB32 target for CO2 reduction in 2020	175 Mt CO2/yr
10a.	Estimated total CO2 reductions from AB32 from 2010 to 2020	875 Mt CO2
11.	Current California yearly CO2 equivalent emissions	470 Mt CO2/yr

a: We carry out the following calculations as an independent check for the total roof area in California. CEC estimates that the stock of existing houses in California is 12.5 M. Assuming that each house has a roof area of about 150 m^2, the total residential area is estimated at 1.9 billion m^2. Accounting for the roof area of nonresidential buildings (approximately the same as the total residential roofs), we estimate a total of 3.8 billion m^2 (3800 km^2) roof area in California. This checks with Row 3.

California Table 2: CO2 avoided by **reducing cooling load** from installing cool roofs on residential and non-residential buildings.

Row	Item	Value
1.	Total residential and non-residential roof area	$4x10^9$ m^2
2.	Fraction all buildings that are air conditioned	0.5
3.	Average air conditioning savings	3 kWh/m^2 yr
4.	CO2 emission per kWh electricity generation	0.5 kg CO2/kWh
5.	Annual avoided CO2 emissions (Row 1 x Row 2 x Row 3 x Row 4)	3 Mt CO2/yr

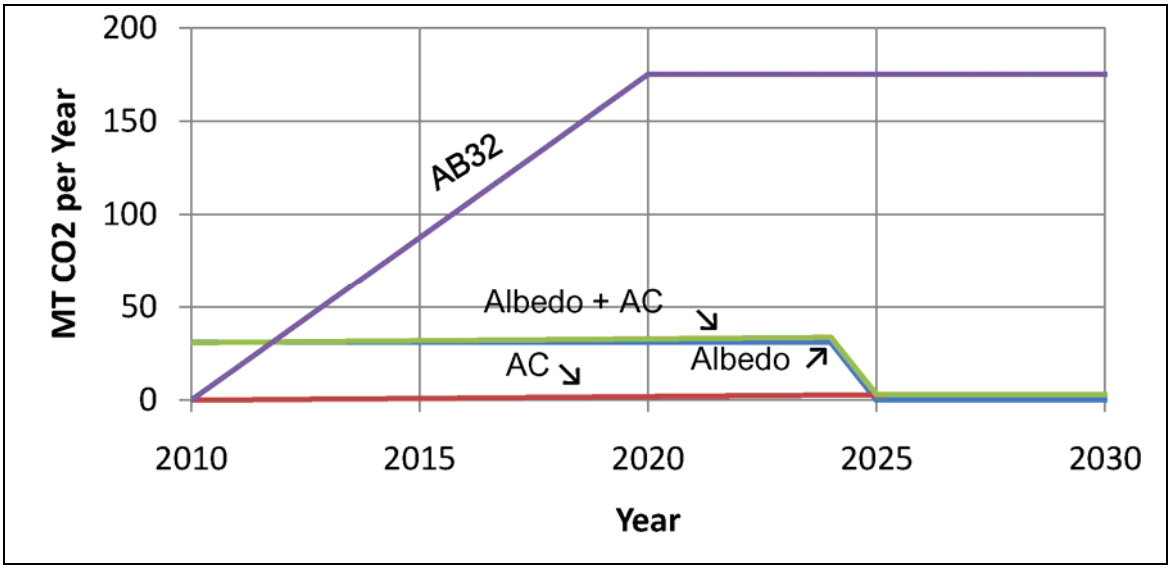

Figure 1. Comparison of CO2 **saving** from AB32 and **offset** by cool urban surfaces (roofs + pavements replaced during a 15-year program). The 'albedo' line is the equivalent CO2 offset (31 Mt CO2/year for 15 years). The lowest line, labeled "AC", reaching only 3 MTCO2/yr in 2025 is the savings from avoided electricity from reduced cooling load from cool roofs. While AC savings is a lucrative measure, it is 10 times smaller than the new albedo consideration.