DRAFT Cool Roofs Roadmap

November 2010

U.S. DEPARTMENT OF ENERGY

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COMMENTS

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ACKNOWLEDGEMENTS

The Department of Energy (DOE) would like to acknowledge and thank all of the participants for their valuable input and guidance provided to develop this Cool Roofs Roadmap. The DOE would like to thank those individuals who participated in the Cool Roofs Roadmap and Strategy Workshop of August 2010 in Washington, DC:

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Table of Contents

1 INTRODUCTION 8

KEY FINDINGS & GENERAL RECOMMENDATIONS 9
BENEFITS 10
STAKEHOLDERS 11
BUDGET 12

2 TECHNOLOGIES 13

COOL ROOFS 13
VEGETATIVE ROOFS 14
COOL PAVEMENTS 15

3 BUILDING LEVEL ROADMAP 16

BARRIERS 16
ACTIVITIES 18
Building Research 18
Technology R&D 19
Enabling R&D 22
Implementation 25

4 URBAN LEVEL ROADMAP 30

BARRIERS 30
ACTIVITIES 32
Urban Heat Island Research 32
Technology R&D 34
Enabling R&D 35
Implementation 37

5 GLOBAL LEVEL ROADMAP 38

BARRIERS 38
ACTIVITIES 40
Global Cooling Research 40

6 INTERNATIONAL ACTIVITIES 43

ACTIVITIES 43
Enabling R&D 43
Implementation 45

7 POTENTIAL AREAS FOR COORDINATION WITH OTHER AGENCIES 47

DRAFT

8 UNADDRESSED OPPORTUNITIES 49

APPENDIX A: STATUS OF COOL ROOF REQUIREMENTS IN NATIONAL BUILDING CODES 50

DRAFT

List of Tables

TABLE 1 BUILDING, URBAN, AND GLOBAL LEVEL BENEFITS 11
TABLE 2 PROPOSED COOL ROOFS BUDGET 12
TABLE 3 ANNUAL ENERGY SAVINGS AND POLLUTION REDUCTIONS OF COOL ROOFS ON COMMERCIAL BUILDINGS 18

List of Figures

FIGURE 1 ROADMAP FOR BUILDING LEVEL ACTIVITIES 17
FIGURE 2 ROADMAP FOR URBAN LEVEL ACTIVITIES 31
FIGURE 3 ROADMAP FOR GLOBAL LEVEL ACTIVITIES 39

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1 INTRODUCTION

The mean annual air temperature of a city with one million people or more can be 1-3°C warmer than its surroundings.[1] This is because urban environments trap more incoming solar radiation and release more waste heat from urban activities. This can be attributed to a wide range of factors including building and urban surface material properties, urban density, minimal urban greenery, and local energy density, among others. This effect can increase urban temperatures, exacerbate air pollution in and around cities, and increase energy demand through heightened air conditioning loads. Diverse strategies have been proposed for mitigation, but those considered most effective increase the urban surface albedo through measures like cool roofs, cool pavements, vegetative roofs, and cool surfaces.[2]

The main goal of this technology roadmap is to maximize the development and implementation of cost effective cool roof and pavement materials and techniques, in order to realize the building energy efficiency improvements, reductions in urban air temperatures, and the global CO_2 reduction benefits of these measures. This goal helps to meet the vision of the Building Technologies Program "…to significantly improve the efficiency of existing and new buildings through the development of conservation technologies, strategies, and practices. The strategic goal focuses on developing cost effective solutions that enable easy adoption in the marketplace for commercial buildings and residences." Furthermore, the DOE believes that "Advanced technologies, such as cool roofs, coupled with a whole building design approach… will enable tomorrow's buildings to use considerably less energy, while also helping to meet our national goals for sustainable development, environmental protection, and energy security."[3]

The roadmap is intended to guide future planning for DOE research and development (R&D) actions and includes the output of a workshop sponsored by DOE on August 9-10, 2010. Key national and international leaders from academia gathered in Washington, DC to explore how to best overcome the obstacles facing urban heat island (UHI) policy implementation and begin to develop a research plan to validate global cooling potential. The panel consisted of several UHI experts and a few climatologists. An additional peer review will be needed to gather more input and finalize the research plan to validate global cooling.

The roadmap should be viewed as a research plan that outlines the steps and describes the collaborative work that must be undertaken. In its final form, the roadmap has been created with the input of, and reviewed by, relevant industry and academia representatives. It will be

[1] Akbari, H., Pomerantz, M., & Taha, H. (2001). Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas. *Solar Energy*, *70* (3), 295-310.
[2] Navigant Consulting, Inc. (2010). *Literature Review of International Studies on Urban Heat Island Countermeasures.*
[3] *Office of Energy Efficiency and Renewable Energy's Building Technologies Program*. Retrieved September 7, 2010, from U.S. Department of Energy: www.eere.energy.gov/buildings

updated and adapted on an annual basis to reflect emerging technologies, changing priorities, and accomplished research.

The organization of this document is derived from the three levels of research being conducted. Cool technologies, including cool roofs, pavements, and surfaces, should be approached from three tiers:

1. Building Level- Focus on the individual building energy savings and improvements in building efficiency that come from cool roof implementation.

2. Urban Level- Focus on mitigating negative UHI effects, such as elevated urban temperatures and increased air pollution, through citywide implementations of cool roofs and pavements.

3. Global Level- The ultimate goal is worldwide implementation of cool surfaces that will lead to a measurable change in the albedo of the earth's surface. This will require international collaboration on research, strategy, and policy to attain full implementation.

This roadmap will describe the research and advances required to realize the full benefits of mass implementation of albedo modification measures, along with key activities and strategies to meet the goals of the building, urban, and global levels.

Key Findings & General Recommendations

Discussions during the August 2010 Cool Roofs Roadmap and Strategy Workshop provided several suggested R&D topics which were discussed and refined by workshop participants. The activities in this roadmap are based on those discussions and R&D topics. There were a number of common themes during the workshop discussions relating to individual tasks or areas of the roadmap, including:

- More theoretical work (R&D activities) to add rigor to current studies, including advanced modeling, validation, and calibration.
- Continued technological development for materials, techniques, and test methods.
- Local-level tools development for use by decision makers.
- Collaboration of efforts and research activities to advance the science.
- Greater outreach efforts to ensure stakeholder involvement.

The workshop identified four categories of roadmap activities, including:

1. Level-specific Research
2. Technology R&D
3. Enabling R&D
4. Implementation

The specific activities in each category are discussed in more detail in the roadmap chapters.

Benefits

Cool technologies offer many benefits at the building, urban and global levels. At the building level, cool roofs provide building energy savings and reduced utility bills for building owners or occupiers. As less solar energy is absorbed by the building's roof, less energy is transmitted into the building. This decreases the air conditioning cooling load and thereby saves energy. Additional benefits include enhanced building thermal comfort and reduction in carbon emissions.

At the urban level, cool surface implementations reduce urban air temperatures. As urban cityscapes increase their overall albedo through large scale implementations, urban surfaces will stay cooler and transfer less heat to the air. The effect will be a lowering of urban surface and air temperatures. Additional benefits from widespread implementation at the urban level include reductions in carbon emissions, reduced peak electricity demand, improved urban air quality, and declining health care costs.

On a global scale, worldwide albedo modification efforts may lead to an increase in outgoing radiation at the top of the atmosphere. This negative radiative forcing increase has been reported to help offset global warming potential by counteracting the positive radiative forcing increases due to elevated atmospheric CO_2 levels.[4] Other benefits of global implementation include improved air quality, reduced health care costs and improved mortality rates from heat stroke, asthma, and breathing complications.[5]

[4] Akbari, H., Menon, S., & Rosenfeld, A. (2008). Global cooling: Increasing world-wide urban albedos to offset CO_2. *Climatic Change*, *95* (3-4), 275-286.
[5] DOE Cool Roofs Roadmap and Strategy Workshop (August 9-10, 2010), Washington, DC.

Table 1 Building, Urban, and Global Level Benefits

	Building Level	Urban Level	Global Level
Benefits	• Building energy savings • Enhanced building thermal comfort • Reduction in carbon emissions	• Reductions in urban air temperatures • Reduced air conditioning loads from ambient air temperatures reductions • Reduction in carbon emissions • Reduced peak electricity demand • Improved urban air quality • Decline in health care costs	• Increased negative radiative forcing that offsets global warming potential • Improved air quality • Decline in health care costs

Stakeholders

Major stakeholder groups at all levels have compelling interests in the promotion and success of cool roofs and pavements.

- Manufacturers can offer differentiated products with environmental benefits and compelling life cycle cost savings for consumers and builders. These benefits allow manufacturers to compete on product differentiation, instead of solely on cost.
- Builders who implement cool surfaces on and around their structures offer attractive economic and non-economic benefits for building owners/occupants. There can be a cost savings on the building's utility bills and known environmental benefits to be reaped by the building's occupants. Utilizing cool surface and building materials will also help builders develop reputations as being environmentally friendly, a niche market in recent years.
- Federal and state governments are all facing pressures to reduce energy use in their jurisdictions. Cool roofs, vegetative roofs, and cool pavements can decrease building energy consumption, thereby decreasing domestic energy use and peak electricity demand.
- Consumers will experience an array of benefits from cool roofs on (and cool surfaces nearby) individual buildings. These countermeasures can lower energy bills, make homes and buildings more environmentally friendly, and make homes and buildings more thermally comfortable. Additional altruistic benefits include improved urban quality of life through air quality improvement, and the potential to mitigate the effects of global warming.
- Utilities can develop urban level cool roof initiatives as part of their energy efficiency programs.

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Budget

The proposed cool roofs budget is $5.41 million in FY2011, as shown below in Table 2.

Table 2 Proposed Cool Roofs Budget

Cool Roof Activities Funding	**FY2011** (in 000s)	**FY2012** (in 000s)	**FY2013** (in 000s)	**FY2014** (in 000s)	**FY2015** (in 000s)
Material Rating: Test Improvement Activities and Code Support	$1200	$1200	$600	$300	$0
Urban Heat Island Analysis and Modeling	1300	1300	1300	1000	600
Research: Next Generation Materials	700	700	700	400	0
Enabling Research and Community Implementation	550	550	800	1000	1000
Global Cooling Modeling and Validation	600	600	950	700	400
International Support Activities	1050	1050	1050	1050	1050
Total	**$5400**	**$5400**	**$5400**	**$4450**	**$3050**

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2 TECHNOLOGIES

There are three major cool technologies: cool roofs, vegetative roofs, and cool pavements.

Cool Roofs

Cool roofs are not only white-colored roofs, but roofing colors and materials that have higher solar reflectance than traditional roofing materials. Cool roofs usually also have a high thermal emittance (the ability to cool through the emission of thermal radiation). This high solar reflectance/high thermal emittance combination minimizes the amount of (heat) energy that is transmitted into a building, resulting in lower cooling loads and decreased demand on building air conditioning units.[6, 7, 8] Other potential benefits include anticipated extended service life through reduced thermal cycling and protection against ultraviolet radiation.[9]

Most traditional roofing materials now have cool alternatives. Some products are cool coatings and membranes (mostly for low slope and metal roofs), while others, like cool-colored shingles (largely for steep slope roofs) have special pigments to reflect near-infrared radiation. Cool roofs may also include loosely-laid roofing membranes covered by a layer of stone ballast or concrete pavers. While not as reflective as white roofs, ballasted roofs increase solar heat removal through thermal inertia and increase cityscape albedo when compared to some alternatives such as dark asphalt roofs.[10,11] In addition, ballasted roofs may offer installed cost advantages, especially for buildings designed to accommodate the additional ballast weight. Finally, ballasted roofs have gained recognition as a cool roof alternative within state and local energy codes.[12]

Cool roofs can be implemented on new construction, roof retrofits (replacements and re-coverings), and roof maintenance projects (coatings and repairs), and both low slope and steep slope, commercial and residential roofs. Cool asphalt shingles are still not cost effective;

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[6] Akbari et al. (2006). *Cool-Color Roofing Material.* California Energy Commission, PIER Building End-Use Energy Efficiency Program.
[7] Taha, H., Akbari, H., Rosenfeld, A., & Huang, J. (1988). Residential Cooling Loads and the Urban Heat Island - the Effects of Albedo. *Energy and Environment*, *23* (4), 271-283.
[8] Santamouris et al. (2001). On the impact of urban climate on energy consumption of buildings. *Solar Energy*, *70* (3), 201-216.
[9] Fraunhofer Center for Sustainable Energy Systems. (July 2010). *Guidelines for Selecting Cool Roofs.*
[10] Desjarlais, A., Petrie, T., Miller, W., Gillenwater, R., and Roodvoets, D. 2006. "Evaluating the Energy Performance of Ballasted Roof Systems," for presentation and publication in the proceedings, 3rd International Building Physics Conference, Montreal, August 27-31, 2006.
[11] Gillenwater, D., Petrie, T., Miller, W., and Desjarlais, A., 2005. "Are Ballasted Roof Systems Cool?" presented at Roof Consultants Institute May 2005 Conference "Cutting Through the Glare" and published in pp. 32-44, RCI Interface, vol. XXIII, no. 9 (September 2005).
[12] 2008 State of California Energy Code (Title 24); 2009 City of Chicago Energy Code; ASHRAE 90.1-2010 (Pending).

however, some cool roofs have little or no price premium and are cost effective on new construction and when installed in the course of the regular roof replacement cycle. It is rarely cost effective to replace a mechanically sound roof with a cool roof.[13] In many U.S. climates, a life cycle cost analysis will show that the cool roof cost premium will be recovered through monthly energy savings on utility bills.[14] Factors that determine the cost effectiveness of a cool roof include building insulation levels, level of air conditioning usage, climate, and cool roof performance over time.[15]

Highly reflective roofs typically lose some of their initial reflectance over time due to weathering, dirt and soot deposition, biological growth, etc. Therefore, aged ratings for solar reflectance and thermal emittance are more representative of true roof performance than initial ratings.[16] In the U.S., the Cool Roof Rating Council (CRRC) is the authority that labels the radiative properties of roofing materials. There are no minimum standards to be included in its ratings and the CRRC maintains a database of all the roofing materials that it tests per the appropriate ASTM International standards.

Vegetative Roofs

Vegetative roofs and urban green areas increase solar heat removal through evaporative cooling and thermal inertia, and shade urban surfaces.[17] Trees, plants, and other vegetative covers on building rooftops prevent much of the sun's energy from being absorbed by the roof and transmitted into the building space, thereby reducing cooling demands.[18] The same is true for ground-level greenery that shades sidewalks and building windows. Vegetative roofs and urban greenery, while not as reflective as white roofs, increase cityscape albedo when compared to some alternative uses of the spaces, such as dark asphalt roofs or blacktop pavement and roadways. They also enhance storm water management, as the trees and vegetation take up and store water.[19] Finally, vegetative roofs sequester CO_2. Vegetative roofs may have significantly higher upfront and maintenance costs but provide many energy, health, and aesthetic benefits.[20] In addition, vegetative roofs may be designed in combination with

[13] Navigant Consulting, Inc. (2010). *Literature Review of International Studies on Urban Heat Island Countermeasures.*
[14] Akbari, H., & Konopacki, S. (2005). Calculating energy-saving potentials of heat-island reduction strategies. *Energy Policy*, *33*, 721-756.
[15] Bretz, S., Akbari, H., & Rosenfeld, A. (1998). Practical issues for using solar reflective materials to mitigate urban heat islands. *Atmospheric Environment*, *32* (1), 95-101.
[16] Berdahl, P., Akbari, H., & Rose, L. (2002). Aging of reflective roofs: soot deposition. *Applied Optics*, *41* (12).
[17] Navigant Consulting, Inc. (2010). *Literature Review of International Studies on Urban Heat Island Countermeasures.*
[18] Bass, B., & Baskaran, B. (March 2001). *Evaluating Rooftop and Vertical Gardens as an Adaptation Strategy for Urban Areas.* Adaptation and Impacts Research Group, Environment Canada and Institute for Research in Construction National Research Council.
[19] Acks, K. *A framework for cost benefit analysis of vegetative roofs: Initial Estimates.* Cost Benefit Group.
[20] Clark, C., Adrians, P., & Talbot, F. B. *Vegetative roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits.* University of Michigan.

reflective roofs and ballasted roofs to reduce the overall cost burden while still achieving significant cooling benefits.[21]

Cool Pavements

Cool pavements are either urban surfaces that have higher than normal solar reflectance, or cool, permeable pavement designs. Pavements include urban streets, driveways, parking areas, and footpaths, such as sidewalks. The range of cool pavement materials usually includes highly reflective coatings, alternative materials with high solar reflectance, and permeable surfaces that retain water and allow evaporation. Such pavements stay cooler in the sun than traditional pavements, keeping the surrounding air cooler. For example, a Lawrence Berkeley National Laboratory (LBNL) demonstration project under construction at the University of California at Davis will compare in a trafficked road the solar reflectances, temperatures and heat flows of four cool pavement designs—asphalt concrete (AC) with a light-colored surface coating, AC with a light-colored chip seal, cement concrete (CC) with 50% of the cement replaced by slag, and CC made with photocatalytic cement—to those of traditional AC and CC. Pavements affect building energy demand through this influencing of air temperature. They are a vital part of any comprehensive UHI mitigation strategy because pavements are estimated to constitute about 40% of urban surfaces.[22] An LBNL study estimated that a change in albedo of 0.15 for cool pavements would induce negative radiative forcing on the earth equivalent to offsetting 20 Gt of CO_2.[23]

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[21] Hoff, J.L., (2009). "New Heat Mitigation and Water Retention Concepts to Expand Green Roofing Demand," Green Rooftops for Sustainable Cities Conference, Awards and Trade Show, Atlanta, GA, June 3-5, 2009.
[22] Akbari, H., Rose, L., & Taha, H. (2003). Analyzing the land cover of an urban environment using high-resolution orthophotos. *Landscape and Urban Planning*, *63* (1), 1-14.
[23] Akbari, H., Menon, S., & Rosenfeld, A. (2008). Global cooling: Increasing world-wide urban albedos to offset CO_2. *Climatic Change*, *95* (3-4), 275-286.

3 BUILDING LEVEL ROADMAP

Building level activities are those that have an impact on the individual building level and improve a building's efficiency, saving energy, lowering carbon emissions, and reducing utility bills. The goal of the building level activities is to maximize cost effective cool roofs.

Barriers

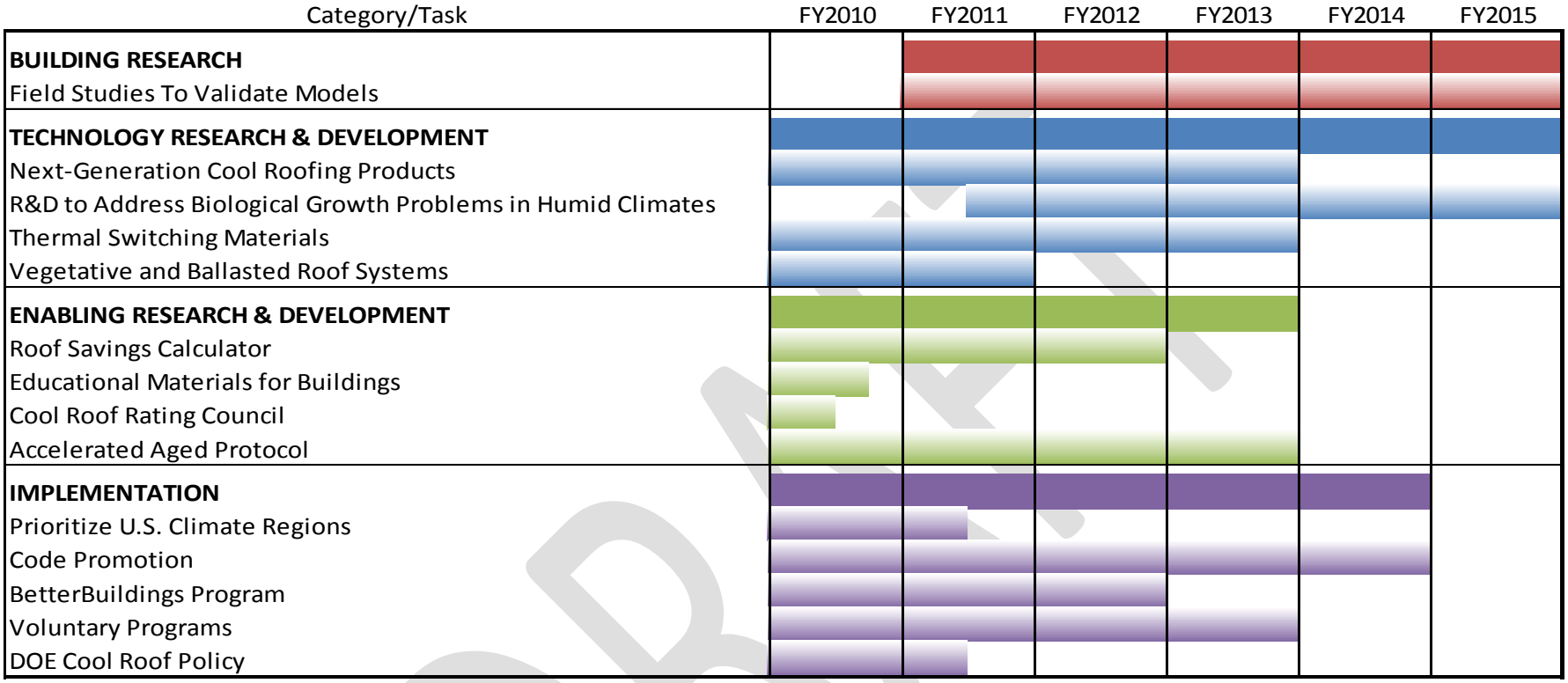
There are several barriers to implementing cool roofs at the building level, including:

- Uncertainty regarding the net energy savings potential and carbon savings for individual buildings.
- Some cool products may cost more than traditional products.
- Reported biological growth problems with cool roof retrofits can cause roofing degradation with time from moisture build-up and molding.
- Methods used to assess the cost of vegetative and ballasted roof technology are incomplete and life cycle cost benefit analyses sometimes fail to consider all relevant factors. There is a lack of research and standards, as well as a lack of public knowledge and awareness of vegetative and ballasted roofs.
- Lack of property owner/developer awareness, motivation, and uptake.
- Lack of manufacturer information to the market on the performance of roofing products.
- Roof reflectance typically declines over time[24] and more accurate ratings are needed to predict lifetime performance. Three years to attain an estimate of lifetime performance is too long to wait to bring new, innovative products to market.
- Increase in service required to maintain these roofing systems.

These barriers are discussed in more detail in the Activities section below, and a roadmap for the solutions to these issues is shown in Figure 1.

[24] Dark roofing products (e.g., black membranes) typically grow more reflective over time because the soil layer is more reflective than the original surface. Asphalt shingles also grow slightly more reflective within the first year or so as oils evaporate from their granules.

Figure 1 Roadmap for Building Level Activities



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Activities

Building Research

Lawrence Berkeley National Lab estimated the benefits of cool roofs on commercial buildings across the U.S. They found that substituting a weathered cool white roof (solar reflectance of 0.55) for a weathered conventional gray roof (solar reflectance of 0.20) yielded the following energy savings and pollution reductions in Table 3.

Table 3 Annual Energy Savings and Pollution Reductions of Cool Roofs on Commercial Buildings[25]

	Unit	Range	Nationwide
Cooling Energy Savings	kWh/m²	3.30 – 7.69	5.02
Heating Penalty	therm/m²	0.003-0.14	0.65
Energy Cost Savings	$/m²	0.126-1.14	0.356
CO_2 Reduction	kg/m²	1.07-4.97	3.02
NO_x Reduction	g/m²	1.70-11.7	4.81
SO_2 Reduction	g/m²	1.79-26.1	12.4
Hg Reduction	μg/m²	1.08-105	61.2

LBNL and Oak Ridge National Laboratory (ORNL) also conducted field studies in Fair Oaks and Redding, CA to prove the energy benefits of cool roofs on residential buildings and benchmark an energy savings tool. They compared energy performance data from three sets of detached, single-family homes with concrete tile, painted metal and asphalt shingle roofs. The thermal performance data proved the superior performance of the cool roof colored materials. Surface temperatures were cooler and caused average heat flows through the roof deck to drop by 20-32%, as compared to the conventional roofs. This resulted in whole house electric energy savings of 10-13% for the cool colored roof materials. The data collected was also used to validate computer codes capable of calculating the heat transfer occurring within the attic.[26]

Field Studies to Validate Models

Additional residential field studies will be needed as new cool roof technologies are developed to both prove the benefits of the technologies and gather data to validate the energy models. The studies will require either building monitoring before and after installation or side-by-side comparisons. And, international field studies will also be conducted through Global Superior Energy Performance (GSEP), as discussed in more detail in Chapter 6.

[25] Akbari, H., & Levinson, R. (2010). Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. *Energy Efficiency*.
[26] Miller, W., Desjarlais, A., Childs, P., Atchley, J., Akbari, H., Levinson, R., et al. (2006). *California Home Demonstrations Showcasing the Energy Savings of Tile, Painted Metal and Asphalt Shingle Roofs with Cool Color Pigments.* California Energy Commission PIER Program.

	Subtasks – Field Studies to Validate Models	Timeframe
1	Conduct field studies of new cool roof technologies	FY11-FY15

Technology R&D

Next-Generation Cool Roofing Products
(Cool Asphalt Shingles, Soiling Effects, and Self-Cleaning Surfaces)

The building level R&D focus for cool roofs is developing new technologies and advancing the state of the art. There is a need to develop next-generation white and colored roofing products with aged solar reflectances superior to those of currently available cool roofing products. Significant barriers to deeper residential market penetration are the popularity of asphalt shingles on residential roofs and the high cost of new technologies. The next generation of envelope surface materials should, therefore, include the most common residential roofing products, namely shingles. The development of a cost effective cool asphalt shingle that reflects a higher percentage of solar radiation (in the near-infrared range) at a lower cost premium would be a critical step in being able to offer consumers the full range of roofing products with cool alternatives.

Engaging a large industrial collaborative group through all stages of development will help attain widespread adoption of these next-generation products by domestic and international manufacturers.

White cool roofing products:
A white roof that stays clean can save up to 50% more energy than a soiled surface. In theory, self-cleaning and/or soil-resistant surfaces will better be able to maintain their initial reflective properties. Advances in white cool roofing products will be made through enhanced solar reflectance via resistance to soiling through chemical and physical modifications, including coating processes and de-soiling or anti-soiling additives. Strategies to incorporate increased soiling resistance include:

- Minimizing the leaching of plasticizers
- Reducing surface roughness and stickiness to discourage contaminant adhesion
- Incorporating titanium dioxide anatase nano-sized particles for photocatalytic "self cleaning" and photoinduced hydrophilicity

LBNL work:
Most roofing materials get soiled fairly quickly once deployed in urban areas. This project is intended to develop new material treatments and coatings that will be more tolerant to soiling and that will exhibit self cleaning attributes, such as new glass coatings. DOE authorized LBNL to do a scoping study in FY10 that includes the requirement to have firm industrial partners, and initiates key technical studies.

Cool-colored roofing products:
Advances in cool-colored roofing products will be made through enhanced solar reflectance via coatings that make more effective use of cool pigments. This includes cool asphalt shingles and concrete tiles with spray coatings. These products will be enhanced by durably and economically applying cool pigments to their surfaces. Novel cool pigments should also be identified and tested. LBNL and ORNL have worked with roofing manufacturers to create cool-colored asphalt shingles, clay tiles, concrete tiles, and metal roofs. These products maintain the aesthetics of colored roofs, but reflect a higher percentage of the sun's near-infrared radiation, keeping the buildings below them cooler. These cool-colored roof products have been tested and successfully demonstrated their energy savings in California climates.

Industry work:
Nanotrons, Corp. (Woburn, MA)
Nano-enabled TiO_2 UV Protective Layer for Cool-Color Roofing Applications
Recently, there has been more interest in darker colored cool roofs because they are believed to be more commercially viable because of their aesthetic appeal for steep sloped roofing applications. Typically these roofs have a reflective layer topped with a pigment layer which is transparent to non-visible light, and so these types of roofs reflect only energy in the Near Infrared (NIR) spectrum. One effective way to do this is with multiple layers: a top pigment layer which is infrared (IR) transparent and an IR reflective bottom layer. However, organic pigments are IR transparent, but not ultraviolet (UV) stable, while inorganic pigments are IR absorbing, and so the top pigment layer deteriorates when exposed to UV light. Nanotrons proposes to address this by developing a UV absorbing protective coating to increase the viability of this type of roof.

Chelix Technologies, Corp (Sunnyvale, CA)
Novel Non-absorbing, Visibly Transparent and Highly NIR Reflective Pigments for Cool Roofing Applications
Chelix proposes to develop a polymer based coating which reflects the NIR, while being transparent to the visible spectrum. This product will use flakes of polymer-based pigments (made from helical Cholesterics) to reflect possibly as much as 80% of NIR radiation. This coating will increase NIR reflection without altering the visual appearance of the roof.

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	Subtasks – Next-Generation Cool Roofing Products	Timeframe
1	Conduct scoping study	FY10
2	Identify and establish industrial collaborations for joint development of next-generation products	FY11-FY13
3	Develop tests to evaluate the performance of de-soiling and anti-soiling additives/functionalities	FY11-FY13
4	Introduce and test self-cleaning functionalities in cool roof products	FY11-FY13
5	Evaluate the effectiveness of anti-soiling methods and accelerated de-soiling of building envelope materials	FY11-FY13
6	Host a workshop on methods and metrics for soiling, de-soiling and anti-soiling of building materials	FY11-FY13
7	Apply and test polymeric coatings to cool-colored products	FY11-FY13
8	Identify and test novel cool pigments	FY11-FY13
9	Prototype high solar reflectance white low slope roofing products	FY11-FY13
10	Prototype improved solar reflectance cool-colored roofing products (tiles, shingles)	FY11-FY13
11	Field test prototypes under varying weathering conditions	FY12-FY13

R&D to Address Biological Growth Problems in Humid Climates

Research is needed to investigate how effective roofs can be designed and maintained to prevent microbial growth that hampers roof performance, especially in humid climates. In warm, moist locations, cool roof surfaces can be more susceptible to algae or mold growth than hot roofs. This is not a major problem, but it can be aesthetically unpleasant and reduce the roof's reflectance. Some roof coatings include special chemicals that prevent mold or algae growth, and these can last for a few years.

Thermal Switching Materials

Thermochromic coatings have the ability to change color depending on their temperature. These materials could be used to save energy during both winter and summer months.[27] It has been shown that thermochromic coatings can have higher solar reflectance values at colored and colorless stages compared to cool-colored and traditional roof surfaces of matched color.[28] More research is needed to confirm material performance characteristics and improve the photodegradation properties of these thermochromic coating materials.

Industry work:
United Environment and Energy LLC (Horseheads, NY)

[27] Navigant Consulting, Inc. (2010). *Literature Review of International Studies on Urban Heat Island Countermeasures.*

[28] Karlessi, T., Santamouris, M., & Synnefa, A. (September 19-23, 2009). Thermochromic energy efficient coatings for buildings and urban structures. *Second International Conference on Countermeasures to Urban Heat Islands.*

Bio-Based Thermochromic Intelligent Roof Coating
In the winter, increased cool roof solar reflectance translates to a heating penalty because solar energy that would otherwise heat the building is now being reflected. This project seeks to develop a thermochromic coating which will reflect solar energy when it is warm outside and absorb solar energy when it is cold. Waste cooking oil and other compounds will be used to create an inexpensive, bio-based thermochromic coating. When this coating is applied (via spray coating) to roof shingles, it forms a durable membrane. This coating will be thermochromic: This will eliminate the winter heating penalty associated with cool roofs while maintaining the benefits of cool roofing when the temperature is high in the summer.

	Subtasks – Thermal Switching Materials	Timeframe
1	Bio-based thermochromic intelligent roof coating	FY10-FY13

Vegetative and Ballasted Roof Systems
The energy impacts of vegetative and ballasted roof systems on commercial buildings are complex and not well understood. Previous studies have looked at the storm water retention and thermal performance of vegetative and ballasted roof systems, but none have evaluated the impacts on rooftop heating, ventilation, and air-conditioning (HVAC) system performance, nor have any studies analyzed the optimal use of roof space. Likewise, previous studies of ballasted roof systems have evaluated thermal performance and impacts on HVAC system performance only for certain localities, but none have evaluated ballasted roofs across a broad array of climates. Having the ability to optimize roof space with respect to whole building energy performance as well as understanding the energy and water performance for various building types and locations is critical.

	Subtasks – Vegetative and Ballasted Roof Systems	Timeframe
1	Evaluation of vegetative and ballasted roofs	FY10-FY11

Enabling R&D

Roof Savings Calculator
The Roof Savings Calculator (RSC) is a roof energy savings calculator for commercial and residential buildings using whole-building energy simulations. It is built upon the DOE-2.1E engine for fast energy simulation and integrates AtticSim for advanced modeling of modern attic and cool roofing technologies. An annual simulation of hour-by-hour performance is calculated for the building properties provided based on weather data for the selected location. The objective is for consumers, contractors, and distributors to use the calculator to estimate the cooling energy savings that can be achieved by installing cool roofing on specific buildings. The

Roof Savings Calculator has replaced the Environmental Protection Agency (EPA) Roof Comparison Calculator and the DOE Cool Roof Calculator.[29]

DOE will continue to expand the scope and improve the usability of the tool. DOE is aware that current leading roof technologies include photovoltaic solar, vegetative roofs, and cool roofs. In the future, DOE will explore ways to help building owners make macro decisions regarding use of their roof space, including adding code compliance and research on thermal mass to the calculator. This additional guidance would help building owners understand their best options and the costs, benefits, and tradeoffs of each technology in their particular climate region and building type.

	Subtasks – Roof Savings Calculator	Timeframe
1	Improve and expand the Roof Savings Calculator. Develop Building Description Language (BDL) models for RSC calculations of four homes and perform simulations using actual weather data.	
2	Benchmark the RSC against the acquired experimental data. Re-factor web service to provide enhanced extensibility, readability, and maintainability of the code while improving web service speed and security.	
3	Add new features to the RSC such as peak-pricing utility models, support for buildings with no HVAC, thermostat set point mechanism, additional building types, graphical display of simulation output, and web input of customer billing data to be used for post-processing and ground-truthing simulation estimations to enhance predictive performance.	

Educational Materials for Buildings

DOE has developed and maintains educational materials for buildings, including a fact sheet and cool roofs selection guide. The fact sheet contains basic information about how cool roofs work and their status in the U.S. It explains the energy savings and the applications to which they apply and offers resources that can be utilized by building owners to help make appropriate decisions regarding cool roofs. It is available on the DOE website at: http://www1.eere.energy.gov/buildings/pdfs/cool_roof_fact_sheet.pdf

To help building owners understand the benefits of cool roofs and how to select the type of cool roof most appropriate for their building, DOE created "Guidelines for Selecting Cool Roofs" in a joint effort between the Building Technologies Program (BTP) and the Federal Energy Management Program (FEMP). The document's purpose is to "help building owners understand how cool roofs work, what kinds of cool roof options are available, and how to determine if cool roofing is appropriate" for their building.[30] It takes into consideration existing

[29] ORNL and LBNL. *Roof Savings Calculator*, Beta Release v0.7. Retrieved September 7, 2010, from http://www.roofcalc.com

[30] Fraunhofer Center for Sustainable Energy Systems. (July 2010). *Guidelines for Selecting Cool Roofs.*

roof conditions to recommend possible replacements and discuss technical options. Furthermore, it explains why cool roofs are important, the criteria they must meet, and the various types of products and materials that can be used for cool roofs. Widespread utilization of these guidelines will ensure that people are using properly formulated and approved cool roofing technologies for their implementations to ensure a greater chance of long term project success. Version 1.2 of this document was publicly released in July 2010 and is available on the DOE website at:
http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/coolroofguide.pdf

	Subtasks – Educational Materials for Buildings	Timeframe
1	Develop and maintain factsheet	FY10
2	Develop and maintain cool roofs selection guide	FY10

Cool Roof Rating Council

All necessary infrastructure must be in place before cool roofs can ever be adopted on a large scale. This includes a ratings infrastructure, voluntary programs, mandatory programs, a legislative framework, means to create awareness/advocacy, availability of products, and pilot projects and demonstrations. The ratings infrastructure is perhaps most important as it provides standardization and a means to differentiate and compare products, giving incentive to manufacturers to compete and create superior products. The CRRC is a non-profit educational organization that has implemented a rating system for cool roof products and maintains an online database of the products it has tested. The ratings program provides both initial and aged values of solar reflectance and thermal emittance, with no required minimum values to be listed. It serves as a central repository for information on product ratings. The CRRC also increases awareness of cool roofs through educational and advocacy efforts. Currently, the CRRC performs aged ratings over a three year period. In the future, they may adopt an accelerated ratings protocol, once such a protocol has been developed and validated.

Accelerated Aged Protocol

Currently, cool roof ratings are certified by the CRRC for roofing surfaces both after being newly manufactured, and after being aged in weathering test farms for three years. Aged values are critical because most cool roof surfaces degrade over time and their performance diminishes (up to 40% within one to two years), although some high-performing products degrade much less than others. Therefore, aged ratings are more accurate in representing how the materials will perform over time. The goal of this project, in cooperation with industry and international partners, is to develop a simulated test protocol that will produce a three-year aged value within a shorter time frame. This project began in FY10, and most of the technical work will be completed in FY11; however, implementation issues will be significant and will continue for several years. The long term goal is to develop an International Organization for Standardization (ISO) standard so that all countries can adopt uniform test standards.

LBNL began lab accelerated soiling studies in FY10 with the help of ORNL, which is conducting microbiological soiling of the samples. Industry partners and trade associations have already been engaged. In FY11, seasonal effects will be examined, and the laboratory accelerated protocols will be completed. In FY12 and FY13, field-weathered samples will be evaluated to validate the accelerated protocols that are developed. If successful, the accelerated soiling protocols will serve as the initial input for the development of the ISO standard on building envelope soiling metrics.

	Subtasks – Accelerated Aged Protocol	Timeframe
1	Develop preliminary accelerated soiling protocols	FY10-FY11
2	Perform laboratory studies of samples, improve characterization of soiled samples, and refine laboratory accelerated protocols	FY11
3	Validate and peer review protocols	FY11-FY13
4	Release final version of accelerated protocols	FY12-FY13

Implementation

Prioritize U.S. Climate Regions

An early step of implementation is to prioritize the climates in which to focus the efforts. Since cool roofs are the focus of the building level, it is necessary to examine and quantify which climates are best suited for their implementation. Cool roofs are most effective in areas where cooling loads are most significant. Therefore, warmer climates with long cooling and short heating seasons maximize the positive impacts of cool roofs.[31] This top priority area overlaps Climate Zones 1-3 of the DOE climate zone map. This represents roughly the lower third of the continental U.S.[32]

[31] Akbari, H., & Levinson, R. (2008). Evolution of cool-roof standards in the U.S.. *Advances in Building Energy Research*, 2, 1-32.

[32] U.S. EIA. (2003). *U.S. EIA Independent Statistics and Analysis.* Retrieved September 15, 2010, from U.S. Climate Zones for 2003 CBECS: http://www.eia.doe.gov/emeu/cbecs/climate_zones.html

Code Promotion

DOE is working with the White Roof Alliance (WRA) to promote code adoption of cool roofs and pavements. The WRA has a comprehensive plan to implement cool roofs domestically and internationally. They will work with state governments, non-profit organizations, professional associations, and foreign governments to include cool roofs and cool pavements in U.S. building codes, international building codes, and pavement codes. The goal is to promote the inclusion of cool surfaces, such as white roofs, in all U.S. and international building and pavement codes globally by 2015. For the next two years, the WRA will focus on domestic building code efforts because the U.S. offers the greatest near-term opportunities for effective promotion, while also exploring the building code landscape in China, India, and other target countries. They will provide technical input into model codes and work in key jurisdictions to secure the adoption of the model codes or more advanced codes. WRA will also further research opportunities for influencing pavement standards and provide technical input to the primary standard setting body, the American Association of State Highway and Transportation Officials (AASHTO).[33]

DOE is also focusing on increasing the adoption of cool roof requirements in national model building codes. Currently, most residential and commercial codes contain incentives for cool roofs (such as lower insulation thermal resistance requirements); however, DOE proposed requirements for cool low slope roofs for climate zones 1-3 in the ASHRAE 2010 code revisions and will propose the same for the International Energy Conservation Code (IECC) in 2012. The status of cool roofs in the various U.S. building codes is summarized in Appendix A: Status of Cool Roof Requirements in National Building Codes.

	Subtasks – Code Promotion	Timeframe
1	Support development of material, test, and building practice standards	FY10-FY11
2	Support the maintenance, improvement, and creation of radiative property test methods	FY10-FY11
3	Support incorporation/improvement of solar reflectance, thermal emittance and/or solar reflectance index requirements for roofs in building energy efficiency standards, including: a. ASHRAE 90.1 (commercial buildings) b. ASHRAE 90.2 (residential buildings) c. IECC	FY10-FY13
4	Evaluate opportunities for further building code work and implementation (e.g., China and India)	FY12-FY14
5	Provide technical input into pavement codes	FY13-FY14

[33] White Roofs Alliance, Strategy and Operations Plan.

BetterBuildings Program

The DOE's BetterBuildings Program provides an excellent collaborative opportunity to boost implementations of cool roofs through retrofits. BetterBuildings encourages communities, state and local governments, private-sector companies, and non-profit organizations to work together on pioneering programs that deliver energy efficiency improvements across neighborhoods throughout the United States. The projects will leverage funding from both the American Recovery and Reinvestment Act (ARRA) and other sources over the next three years to retrofit hundreds of thousands of homes and businesses across the country. The BetterBuildings partnerships will support new energy efficiency retrofit markets throughout the country by being innovative in their approaches, striving for improvement, bringing real solutions to market, and creating sustainable initiatives to increase energy efficiency in all types of buildings into the future.[34]

DOE can combine cool roofs with the next generation of roofing systems through the BetterBuildings Program. Cool roofs are not yet cost effective for steep slope roofs; however, if combined with large energy savings projects, they may become cost effective through lower cost or a combination of UHI/global cooling benefits. DOE can also conduct technical and cost studies in coordination with the BetterBuildings Program in hot and mixed climates.

	Subtasks – BetterBuildings Program	Timeframe
1	Support cool roof implementations	
2	Conduct technical and cost studies in hot and mixed climates	

Voluntary Programs

Many of the current cool roof implementations are due to participation in voluntary programs, such as Leadership in Energy and Environmental Design (LEED) and ENERGY STAR. LEED offers a UHI mitigation credit for a cool roof,[35] though this credit is not mandatory in order to become LEED-certified. ENERGY STAR, a voluntary program managed by DOE and EPA, also offers a cool roof label. The overall program aims to capture the most efficient products and sets minimum requirements for both initial and aged solar reflectance values. For products to be listed by ENERGY STAR, they must meet established minimum requirements.

Also, the Center for Environmental Innovation in Roofing is currently working to pilot their new RoofPoint program. The program is the first comprehensive roof rating system for assessing and selecting sustainable roof systems, not just cool roofs. This voluntary program uses current state-of-the-art as a baseline to evaluate roof system lifecycle performance. Of the program's five functional areas of design guidelines and assessment, the Energy Management

[34] U.S. DOE EERE. *BetterBuildings*. Retrieved September 7, 2010, from U.S. DOE Energy Efficiency and Renewable Energy: http://www.eere.energy.gov/betterbuildings/

[35] Akbari, H., & Levinson, R. (2008). *Status of cool roof standards in the United States.* California Energy Commission Public Interest Energy Research Program.

area includes a roof surface thermal contribution criteria that encourages optimizing net energy efficiency by installing high albedo, ballasted, or vegetated roof surfaces.

Utility rebate programs incentivize building and home owners to meet or exceed performance standards. Examples of incentives for cool roofs include tax credits, rebates, and grants for projects. Utility incentive programs for cool pavements include building tax incentives and property tax credits, expedited permitting, and grants. The CRRC maintains a list of both utility rebate programs and voluntary programs on its website: http://coolroofs.org/codes_and_programs.html

	Subtasks – Voluntary Programs	Timeframe
1	Support incorporation/improvement of solar reflectance, thermal emittance, and/or solar reflectance index requirements for roofs in voluntary programs, including: a. LEED b. ENERGY STAR c. RoofPoint d. Utility Rebate Programs	FY10-FY13

DOE Cool Roof Policy

The Federal Government is the largest consumer of energy in the nation.[36] The DOE must set the example in energy and greenhouse gas stewardship for the rest of the government. Because cool roofs provide significant energy savings and environmental benefits, they should be used whenever practicable. For this reason, effective June 1, 2010, per an internal memorandum from Secretary Chu, roof replacements and roofs for new construction for all DOE facilities shall be cool roofs unless determined uneconomical by a life cycle cost analysis (unless the project already has CD-2 approval). Secretary Chu sent letters to the heads of all other U.S. Federal agencies asking them to follow suit. As a leading example, the DOE Forrestal building in Washington, DC is being retrofitted with a cool roof that is scheduled to be complete at the end of summer 2011.

As directed by Secretary Chu, DOE has been working with FEMP to develop similar policies with other federal agencies. FEMP has assembled a list of cool roof resources to help Federal energy managers learn more about cool roof technologies and how they can be deployed. This resource list includes overviews of cool roof technologies, buying guides providing instructions for Federal procurement of cool roof technologies, Federal case studies of cool roof technologies,

[36] "President Obama Sets Greenhouse Gas Emissions Reduction Target for Federal Operation." (2009, January 29). The White House, *Office of the Press Secretary*. Retrieved August 1, 2009 from http://www.whitehouse.gov/the-press-office/president-obama-sets-greenhouse-gas-emissions-reduction-target-federal-operations

and information on deployment activities. The cool roof resources can be found at: http://www1.eere.energy.gov/femp/features/cool_roof_resources.html.

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4 URBAN LEVEL ROADMAP

Urban level activities have cumulative impacts beyond individual building efficiency and work to mitigate heat island effects and improve urban air quality. The focus at the urban level is cool roofs and pavements and the goal is to cool cities to save energy and reduce carbon emissions.

Barriers

There are several barriers to implementing cool roofs and pavements at the urban level, including:

- Uncertainty regarding the energy savings potential and carbon savings for cities and urban areas.
- Uncertainty regarding the other benefits of UHI countermeasure implementation.
- Need to study and assess the possibility of "unintended consequences."
- Too few pavement cost-benefit analysis studies have been undertaken. There is insufficient research and modeling of pavement benefits.
- Concern about the negative unintended consequences of roofs and pavements, such as inadvertently increasing taller building cooling loads through increased reflectance of shortwave radiation from shorter buildings.
- Policy makers need tools to quickly determine the costs/benefits of the adoption of cool technologies. They need the ability to quickly assess the magnitude of the UHI effect in their locality, and measure their progress in combating it.
- Lack of general awareness and uncertainty around the effects and benefits of previous urban implementations.
- Need for coordinated efforts to increase awareness/publicity and share UHI mitigation strategies.
- Need for more accurate estimates of the effects of various UHI strategies.
- Skepticism and lack of confidence in urban model projections.
- Uncertainty regarding pollution abatement and the corresponding financial benefits.

These barriers are discussed in more detail in the Activities section below, and a roadmap for the solutions to these issues is shown in Figure 2.

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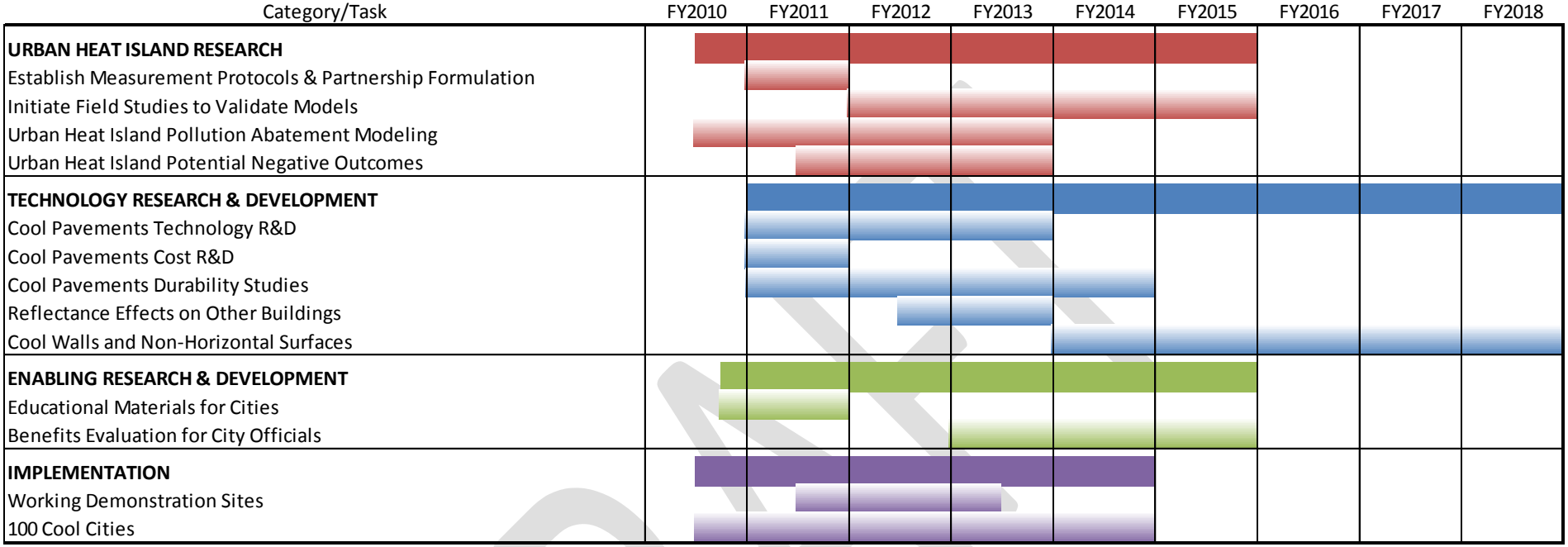
Figure 2 Roadmap for Urban Level Activities



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Activities

Urban Heat Island Research

A major finding from the peer review panel in August 2010 was the need for a comprehensive international study to derive and validate urban temperature reduction as a result of higher albedo surfaces, cool roofs, and cool pavements. The international distinguished panel discussed and debated the benefits of direct global cooling from higher albedo surfaces, along with the traditional benefit of urban temperature reduction. Urban temperature reduction provides three key benefits: pollution formation reduction, reduction of cooling loads (energy efficiency), and global cooling that can be converted to an equivalent carbon reduction potential. Thus, if temperature reduction can be derived and validated, then it will provide the key to monetizing the full benefits of higher albedo urban landscapes. However, to derive and validate urban temperature reductions will not be easy. While there is extensive UHI research, there are not comprehensive studies to accurately quantify temperature reduction from varying mitigation strategies. Also, significant UHI modeling issues still exist that need to be addressed.

Establish Measurement Protocols and Partnership Formulation

The approach will be to develop a uniform set of test conditions and analytical requirements with test target areas of approximately one square kilometer. Measuring stations will assess urban temperatures before and after mitigation strategies are deployed. The first phase of the project will be to develop the test conditions and measuring protocol, and then vet the test conditions and protocol with universities and international partners. Developing the uniform test conditions and measuring strategy will be conducted in FY11, along with the initiation of project and partner formulation.

	Subtasks – Establish Measurement Protocols and Partnership Formulation	Timeframe
1	Develop test conditions and measuring protocol	FY11
2	Vet test conditions and protocol with universities and international partners	FY11

Initiate Field Studies to Validate Models

Working to develop research partners, similar studies would be pursued in multiple climatic and urban areas of the world. Several U.S. locations would conduct the study along with China, India, Europe and other areas, if partners are found.

	Subtasks – Initiate Field Studies to Validate Models	Timeframe
1	Formulate partnerships	FY12
2	Conduct similar studies in multiple climatic and urban areas	FY12-FY15

Urban Heat Island Pollution Abatement Modeling

When moving from building-level impact to city-level impact for cool roofs, urban heat island mitigation is the important issue to assess. There are two main benefits that need to be analyzed: pollution formation reduction (including smog) and urban temperature reduction. DOE requested proposals on pollution abatement modeling to monetize the benefits. The models would be used by utilities to include the analysis of the monetary value of pollution mitigation when assessing the issuance of rebates. Pollution abatement benefits could also be used by code officials in determining public policy. LBNL is conducting a scoping study that will address macro technical issues, planning, and scheduling before committing to the full proposal. LBNL vetted its initial plan with the international scientific peer review panel that was convened in August 2010.

To more exactly determine the benefits of cool roofs and pavements, there is a need to quantify the changes in energy use, ozone, and particulate matter resulting from implementations (aerosol effects must also be thoroughly considered). Monetizing the indirect benefits requires determining the economic value of the energy savings, health care burden reduction, and global warming potential reduction that result from the increased use of cool roofs and pavements. Meteorological impacts are very location dependent and, along with emissions changes, are highly influential in determining pollutant loading. Emissions changes can be estimated from energy demand reduction and knowledge of a region's generation fuels mix. Energy costs, health care costs, global warming potential reduction, and CO_2 offsets can then be calculated from changes in energy use and pollutant loading, and the reduced rate of smog formation from the decrease in outside air temperature. Pollution costs can be monetized by determining health care costs and CO_2 offsets from energy reduction. Most critically, calculating the global warming potential reduction will allow one to quantify interactions between air quality and climate. These calculations will consider CO_2, ozone, and particulate matter changes together, and can express their impact in terms of CO_2 equivalents and potential CO_2 offsets, the necessary foundation to be considered for voluntary carbon markets.

	Subtasks – Urban Heat Island Pollution Abatement Modeling	Timeframe
1	Conduct scoping study and vet with international scientific peer review panel	FY10
2	Develop cool roof and pavement scenarios for regions to be simulated	
3	Build models and conduct diagnostics and testing of the models	
4	Conduct simulations to determine changes in air temperature and air quality that result from cool roof and pavement implementations in different areas of the country	
5	Determine changes in energy use, pollutant loading, and global warming potential reduction	
6	Assess uncertainty and estimate variability in different geographic regions	

Urban Heat Island Potential Negative Outcomes

The potential negative effects or unintended consequences of mass UHI implementations must also be addressed. These possibilities need to be fully evaluated, including:

- What if we cool cities so much that urban circulation patterns change?
- What if particulate matter (PM) levels do not change as expected?
- What about the potential ill-health impacts of cool roof materials (such as polyvinyl chlorides (PVC), dioxins, and phthalates)?

Technology R&D

Cool Pavements Technology R&D

There are few options today to make asphalt concrete cool, and making cool cement concrete can be challenging in places that lack light-colored fine aggregate. R&D is also needed on self-cleaning pavements.

	Subtasks – Cool Pavements Technology R&D	Timeframe
1	Conduct technology R&D for cool concrete	FY11-FY13
2	Conduct R&D on self-cleaning pavements	FY12-FY13

Cool Pavements Cost R&D

Urban albedo modification as a means to cool cities is not realistic without implementing cool pavements because they make up such a significant portion of urban landscapes. Analyses of the lifecycle costs and carbon footprint of the different types of cool pavements (concrete versus asphalt) are needed to evaluate the true impacts and cost effectiveness of cool pavement implementations. Also, a single rated methodology for determining cool surface lifecycle costs does not exist and should be developed.

	Subtasks – Cool Pavements Cost R&D	Timeframe
1	Conduct analyses of the lifecycle costs and carbon footprint of cool pavements	FY11

Cool Pavements Durability Studies

More studies are needed regarding the durability of cool pavements. It is critical that field experiments are conducted on implemented cool pavement designs to understand the effects of weathering, dirt, pollution, use, age, etc., on the performance of cool pavement technologies.

Further research in the form of field experimentation and data collection is required in a range of operating conditions and climates to determine the exact impacts on pavement temperatures and, therefore, UHI mitigation capabilities.

	Subtasks – Cool Pavements Durability Studies	Timeframe
1	Conduct field experiments on the cool pavement implementations	FY11
2	Conduct additional field experiments over a range of operating conditions and climates	FY12-FY14

Reflectance Effects on Other Buildings and Shading Effects on Cool Surfaces
An emerging issue of unknown consequence is increased reflectance from lower level buildings with highly reflective roofs. As cool roof implementations become more common, there will be increasing incidence of shorter buildings with cool roofs reflecting additional shortwave radiation into the windows of taller buildings. Potentially, this increased reflectance could have heating and glare impacts on any taller buildings, thereby diminishing the reduced cooling load benefits of cool roofs. This same issue is also of concern for highly reflective pavements that will reflect shortwave radiation back at buildings and windows. If, or to what degree, this concern is an issue is unknown and needs to be studied.

In urban areas and city centers, some low roofs, pavements, and other surfaces are only exposed to the sun for a fraction of daylight hours. This thereby diminishes the effectiveness of implementing cool surfaces in these applications. These shading effects must be reviewed on a case-by-case basis for the intended application and should be considered in a lifecycle analysis to determine the most effective energy efficiency improvement measure to implement.

Cool Walls and Non-Horizontal Surfaces
Walls and other non-horizontal surfaces are important facets of the urban landscape at lower solar incidence angles. As urban models advance to include changing albedo over the course of the day, walls and non-horizontal surfaces may warrant consideration for modeling at the urban scale.

Enabling R&D

Educational Materials for Cities
Cities and city leaders need to be made more aware, and have a better understanding, of the benefits of cool technologies. In response to the need for more information and tools, DOE will provide educational materials and support to cities. Educational materials that communicate

research results, such as case studies and brochures, will help city leaders make relevant, informed decisions about implementing cool roofs and pavements.
DOE will work with local jurisdictions to conduct analytical studies and policy research that articulates the non-energy benefits of cool roofs to enable policy formulation and implementation for urban heat island mitigation and global cooling from higher albedo urban surfaces. Analyses and enabling research will include pollution abatement and health benefits from quantitative and qualitative perspectives. The key deliverables from the research will be policy case studies that provide lessons learned from the policy arena with a variety of local governments based on climate and political perspective variability.

DOE is also developing a policy maker brochure. An informational brochure directed at policy makers and leaders will be a valuable promotional tool to show the current status of urban heat island mitigation technologies and explain the work remaining to be completed in the field. It would also outline the expected lifetime costs and the benefits of the technologies in comparison to other energy efficiency options. This tool would be distributed to major stakeholders and decision makers, such as mayors and city officials, who have the ability to promote large scale implementations and programs. The brochure would include evaluations of the competition for roof space to show the degree of benefit in different urban situations and climates. This will help cities decide the best use of their roof space. Officials need to be able to quantify the benefits of potentially costly implementation projects to their constituencies. These types of local-level tools will help articulate the value proposition of cool roofs and pavements.

	Subtasks – Educational Materials for Cities	Timeframe
1	Collaborate with local jurisdictions to conduct analytical studies and policy research	
2	Develop policy case studies	
3	Develop a policy maker brochure	

Benefits Evaluation for City Officials
A standard methodology for cities, states, or urban areas to track cool surface installations is needed to follow the progress of programs and UHI mitigation. Cities want to know how they can measure the effects of the heat island mitigation measures that they implement. Also, a city will want to be able to calculate the carbon savings it has experienced due to the level of cool surface implementation that it has attained. The methodology would compare the number and scale of implementations to the resulting energy savings, and then calculate the carbon savings.

Implementation

Working Demonstration Sites

Demonstration sites can serve as a valuable tool to display and prove the benefits of cool roofs and pavements to decision makers and stakeholders. These real world simulations can help stakeholders see and understand the full lifecycle of these cool surfaces and the associated costs and operations necessary to maintain them. Demonstration projects are found to be most effective when they target high-visibility projects to attract attention, measure benefits to illustrate the reason to act, and convey lessons learned to allow for replication and improvement.[37]

100 Cool Cities

DOE is also working with the White Roofs Alliance and Local Governments for Sustainability (ICLEI) to develop city building policies on cool roofs through the 100 Cool Cities Initiative. The White Roofs Alliance is building and supporting a network of municipal governments dedicated to the implementation of white roofs. The 100 Cool Cities initiative is part of the WRA strategic plan, and focuses on recruiting and obtaining commitments from 100 major cities across the globe by 2015, with widespread installation of cool surfaces by 2020. Three cities have already joined the network: Athens, Taipei, and New York.

WRA will host an annual conference where partners can learn about the latest scientific research and share findings, success stories, and lessons learned from demonstration projects. WRA will also work with partners to develop criteria for a cool city certification that cities can achieve, build a best practice database, provide technical assistance and support, and provide access to scientific literature related to cool roofs and pavements.[38]

	Subtasks – 100 Cool Cities	Timeframe
1	Recruit 100 Cool Cities partners	FY10-FY11
2	Hold workshops for target cities	FY10-FY14
3	Develop partnerships with ICLEI and other organizations to encourage the inclusion of cool surfaces in municipal level climate plans	FY10-FY14
4	Develop technical assistance that can be deployed globally	FY11-FY14
5	Build best practices database	FY12-FY14

[37] EPA Climate Protection Partnership Division. (October 2008). *Reducing Urban Heat Islands: Compendium of Strategies.* U.S. EPA Office of Atmospheric Programs.
[38] White Roofs Alliance, Strategy and Operations Plan.

5 GLOBAL LEVEL ROADMAP

Global level activities mitigate global warming through increased negative radiative forcing. The goal at the global level is to verify and validate the global cooling potential of cool surfaces.

Barriers

There are several barriers to verifying and validating global cooling potential of cool surfaces, including:

- Few studies estimating the global potential of negative radiative forcing.
- No studies assessing if potential albedo increases are achievable.
- Lack of measured data of the radiation impacts.
- Skepticism and lack of confidence in global model projections.

These barriers are discussed in more detail in the Activities section below, and a roadmap for the solutions to these issues is shown in Figure 3.

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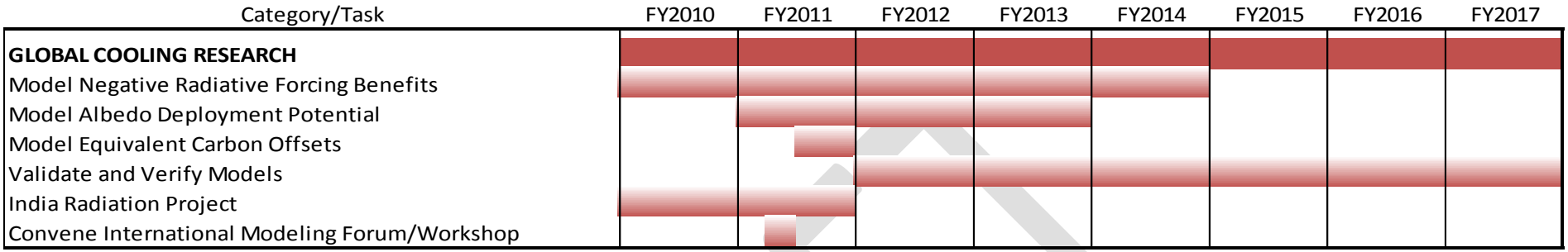
Figure 3 Roadmap for Global Level Activities



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Activities

Global Cooling Research

Model Negative Radiative Forcing Benefits

There are three studies to date that assess the global potential of negative radiative forcing.[39, 40, 41] The first of which was the 2008 LBNL study headed by Akbari that found that increasing the albedo of pavements by 0.15 and roofs by 0.25 could increase the worldwide albedo by 0.0003.[42] However, more advanced modeling of these benefits from multiple independent research groups is needed to validate these studies before major policy decisions can be made.

Advanced modeling may include tailoring models to specific locations, more accurate characterization of urban areas, and more detailed modeling of radiative transfer. The development and use of more accurate urban area characterizations will improve assessments of the global cooling potential of cool roofs and pavements in cities.

Model Albedo Deployment Potential

The three recent studies assessing the global potential of radiative forcing make assumptions about the potential to increase worldwide albedo, yet there have been no studies of whether these albedo increases are achievable. Instead, the approach has been to assume that all surfaces are available for modification and albedo increase. While this may be true for many cities in the United States, other locations, such as Africa and the Middle East, already have many high albedo buildings, so the potential for albedo increase is lower.

Model Equivalent Carbon Offsets

The 2009 LBNL study headed by Akbari found that increasing the total worldwide albedo by 0.0003 would have the equivalent effect of offsetting 44Gt of CO_2.[43] More advanced modeling of the carbon savings from multiple independent research groups is needed to validate this study.

[39] Akbari, H., Menon, S., & Rosenfeld, A. (2008). Global cooling: Increasing world-wide urban albedos to offset CO_2. *Climatic Change, 95* (3-4), 275-286.
[40] Menon et al. (2010). Radiative forcing and temperature response to changes in urban albedos and associated CO_2 offsets. *Environmental Research Letters, 5*.
[41] Oleson, K., Bonan, G., & Feddema, J. (2010). Effects of white roofs on urban temperature in a global climate model. *Geophysical Research Letters, 37*.
[42] Akbari, H., Menon, S., & Rosenfeld, A. (2008). Global cooling: Increasing world-wide urban albedos to offset CO_2. *Climatic Change, 95* (3-4), 275-286.
[43] Ibid.

Validate and Verify Models
To establish credibility for the negative radiative forcing models and studies, they must be validated and verified by experimental results that match the model outputs, as well as independent third parties. This independent validation is a critical step in helping to create support for future policy decisions and monetizing benefits.

Modeling output is only as good as the data input into the model, and so more accurate data is needed for these models. This data should come from measurement campaigns, observation, experiments, and demonstration sites that are developed to explore cool surface effects. There should also be more cross-disciplinary study that improves model data accuracy. For example, global cloud cover models are readily available and should be applied to the studies. Models should be run under longer time scales and with greater spatial resolutions. Enhanced modeling rigor and validation of modeling techniques is needed. To date, the focus of most studies has been on North American climates. In order for global estimates to be accurate, testing, modeling, and simulation of cool roofing and cool pavement technologies needs to be performed for a greater range of climate types found throughout the world.
Input sensitivity analyses are needed to determine the variability and range of expected results from global studies of albedo modification. Such analyses would show how much expected results would change based on changes in the assumptions made in the studies.

India Radiation Project
LBNL is conducting a scoping study of a radiation measurement study in India in FY10-FY11. Leveraging the Office of Science's $5-10 million study over three years to measure radiation impact of aerosols and other pollutants, LBNL proposed to enhance this study by assessing the radiation impact before and after roof surface albedo is increased. Expected measurement sources include satellite data, special aircraft, and radiation measurement balloons, and stationary equipment. A detailed scoping effort and budget justification are expected as part of the key deliverable. This study could include building efficiency measurements, as well as radiation impacts, but will probably not be able to measure urban heat island impacts due to the size of the test area and inability to retrofit privately owned buildings. While this study does not validate UHI, the peer review panel thought it offered significant benefit to the understanding of radiation impacts.

	Subtasks – India Radiation Project	Timeframe
1	Conduct scoping study	FY10-FY11

Convene International Modeling Forum/Workshop
There is growing global interest in albedo modification research and modeling because of its international implications and benefits. It would therefore be valuable to bring together these groups to share knowledge and ideas, and establish collective priorities to advance the science.

Bringing together people from across different fields would help with knowledge transfer of the latest research and state of the art tools in related fields.

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6 INTERNATIONAL ACTIVITIES

International activities focus on city- and national-scale implementations of cool roofs and pavements all around the world. The goal is to create international partnerships to realize the macro-scale benefits of cool surfaces.

There is a much greater opportunity for cool roofs internationally than in the U.S. since many cities have much hotter climates than the U.S. Furthermore, labor for coating applications, a major component of installed cost in the U.S., is much lower in countries like India and China. The DOE Initial Opportunity Assessment Study and the WRA plan demonstrate a need for an aggressive international effort. Also, the Assessment of International Urban Heat Island Research found that working with the international community can reduce costs, increase R&D, and create markets for U.S. technologies and services all while stimulating global warming mitigation. [44]

The main focus of the international activities will be to provide technical support in the establishment of rating systems and international codes, case studies, training, cost calculators, educational materials, etc. China and India are the first tier of interest, followed by the second tier, including Brazil, the Association of Southeast Asian Nations (ASEAN), the Middle East, Mexico, Southern Europe, Australia, and Japan. Based on opportunities and international partner's efforts, technical support will be provided by labs, non-governmental organizations (NGOs), and universities.

Activities

Enabling R&D

International Codes & Standards Support

New international standards for accelerated weathering and soiling of building envelope materials are needed. This will require actively engaging scientific and industrial partners in the development of the international standards. Also, initiating an international roof rating system will require collaboration between the U.S. CRRC and the E.U. Cool Roofs Council (CRC). This international rating system will build on the U.S. and E.U. programs and will help support the development of international standards for accelerated exposure. The accelerated soiling protocols developed in the U.S. will serve as initial input for the development of international standards that will facilitate further adoption and use of advanced building envelope surfaces. Such international efforts are beneficial domestically in that they promote international markets for American products and ensure that research efforts are not duplicated. The U.S.-E.U. Energy Council has recognized this need and has begun to engage

[44] Navigant Consulting, Inc. (2010). *Literature Review of International Studies on Urban Heat Island Countermeasures.*

both domestic and international partners, with an ultimate goal of creating a world ISO test procedure.

In collaboration with DOE in coming years, WRA will begin focusing on building codes in China, India, and other target countries. These areas have high population densities, growth in buildings, and tropical climates, which present great potential for cool roof benefits. WRA will work to provide technical input into the existing model codes in these countries. Further, they will work to ensure the adoption of the model codes, or advanced codes, in key jurisdictions within these regions.

	Subtasks – International Codes and Standards Support	Timeframe
1	Actively participate in international standards organizations	FY10-FY13
2	Host a forum in partner countries to generate a standards development plan for the next three years. Provide training and examples of successes based on previous work.	FY10-FY13
3	Engage scientific and industrial partners, both domestically and internationally	FY10-FY13
4	Promote international standardization efforts	FY10-FY13
5	Support the development of new international standards for accelerated aging of roofing materials	FY10-FY13
6	Support the development of ISO standards for radiative property test methods	FY10-FY13
7	Collaborate with the U.S. CRRC and E.U. CRC to initiate an international cool roof rating system, with a focus on use in China and India	FY11-FY13

International Case Studies

Most importantly, case studies are needed from international implementation projects. These case studies should focus on the logistics, results, and lessons learned from international cool roof and pavement implementation projects. These case studies should serve as building blocks for future implementations and create publicity for successful implementations, while helping to avoid duplicating mistakes. Data is also needed from the case studies, such as building efficiency measurements, urban temperature impacts, and radiation impacts.

GSEP is a new public-private partnership announced at the July 2010 Clean Energy Ministerial designed to cut energy use and greenhouse gas emissions in industrial and commercial facilities around the world. The partnership, still under development, will cut energy use, reduce greenhouse gas emissions and pollution, save money, and create jobs. A major effort will be the creation of case studies for both sectoral and cross-sectoral technologies. Sectoral technology case studies will focus on specific energy-intensive sectors and promote the deployment of best available efficiency technologies and best practices. Cross-sectoral technology case studies will facilitate the deployment of specific energy-saving technologies, such as cool roofs.

International Energy Agency (IEA) Cool Roof and Envelope Pathway

To implement a policy pathway, DOE will co-fund the International Energy Agency to initiate this policy pathway. Currently, the IEA is working on pathways for Appliance Standards and Building Certification.

	Subtasks – IEA Cool Roof and Envelope Pathway	Timeframe
1	Initiate a policy pathway	FY10-FY11

Implementation

International Forum to Share Implementation Experience

Currently, there is little international coordination and data sharing, despite the fact that many different research communities are active at the urban scale in places like the U.S., Japan, and Europe. The U.S., Canada, and Northern Europe have all made significant investments in building envelopes, and much work has been done in Germany and Japan on vegetative roofs and urban planning. Countries like India already have cool roof measures in policies, but still lack the necessary cool roof infrastructure.

Bringing together an international forum would allow cities and researchers to better coordinate their efforts and gain a broader perspective on what others are already doing. It would provide a means to gather groups of stakeholders that can draw from their experiences in trying to implement cool roof and pavement projects to move the research community forward.

China and India

Winbuild has played a major role in window testing and rating implementation in India, China, and many other countries. In FY10 and FY11, Winbuild and CRRC are working together to implement cool roofs in China and India. They have reached agreement to form a working group with China and extensive discussion has taken place to work with India. The first major meeting with China will be a cool roof workshop in Shenzhen on October 15, 2010. Winbuild and CRRC also participated in the Asia-Pacific Economic Cooperation (APEC) Cooperative Energy Efficiency Design for Sustainability (CEEDS) Building Code workshop in early September and will also participate in the Japanese-U.S. Zero Energy Buildings (ZEB) Workshop on October 20- 21, 2010. They will also participate in many other venues based on funding availability. Winbuild has played a major coordination and management function for windows and this is expected for cool roofs. Developing cool roof ratings is a fundamental first step in implementation.

	Subtasks – China and India	Timeframe
1	Establish working groups with China and India	FY10
2	Hold cool roof workshops in China and India	FY11

APEC/ASEAN

Pacific Northwest National Laboratory (PNNL) is helping with APEC implementation issues and helps support the Energy Working Group, Energy Efficiency Expert Group. They also have participated in the APEC CEEDS Building Code Workshop. They will participate in other meetings in FY11.

	Subtasks – APEC/ASEAN	Timeframe
1	Support APEC implementation issues	FY10-FY11
2	Participate in the APEC CEEDS Building Code Workshop and other meetings	FY10-FY11

Jordan and South Africa

The National Fenestration Rating Council (NFRC) will provide training and host workshops in Jordan and South Africa. Previously, similar workshops have included cool roof awareness education and will continue with this effort.

	Subtasks – Jordan and South Africa	Timeframe
1	Provide training and host workshops in Jordan and South Africa	FY10-FY11

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7 POTENTIAL AREAS FOR COORDINATION WITH OTHER AGENCIES

Several potential areas for coordination between the DOE and other U.S. government agencies were identified in the workshop to advance cool roofs and pavement research and implementation.

Environmental Protection Agency

EPA's Heat Island Reduction Initiative focuses on outreach efforts to provide communities with the tools and information they need to develop UHI mitigation projects, programs, and policies. DOE, in conjunction with EPA, can capitalize on these outreach efforts to grow awareness among stakeholder groups and garner support for urban-scale studies and experiments.

In addition, the EPA is also already trying to integrate energy efficiency measures into the planning for regulation under the Clean Air Act. A long term goal would be to try to incorporate cool roof and pavement measures into the Clean Air Act for their smog reduction and urban air quality improvement benefits.

National Science Foundation (NSF)

The NSF has recently seen its budget grow from ARRA funding, providing an opportunity for the research community to take advantage via projects related to heat islands and urban-scale mitigation measures. One example of research that can be leveraged is the funding provided to opportunities under the Urban Long-Term Research Areas: Exploratory Research Areas (ULTRA-Ex). This funding provided support to conduct interdisciplinary research on the dynamic interactions between people and natural ecosystems in urban settings. Examples of relevant projects that were funded included explorations of urban forestry, urban sustainability, and urban development. The results of these projects should be shared with the larger research community as part of an effort to encourage the sharing of data and cooperation between research groups.

Department of Transportation (DOT)

DOT currently conducts much of its own research on advanced concrete and pavement designs through the Federal Highway Administration's (FHWA) Office of Pavement Technology. This office performs asphalt and concrete pavement technology research, with some additional focus on sustainability, which are areas from which the cool pavements community can greatly benefit.

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Integrating DOE and DOT at a higher level to align their goals could lead to incorporating energy concerns into the FHWA's research. FHWA could not only work to achieve more durable and cost effective pavements, but could also begin to look at heat and energy issues related to pavements and could pursue advanced materials that align with DOE goals at the urban level.

National Aeronautics and Space Administration (NASA)

Urban 4D is a NASA-funded effort to look at select cities in target climates and deploy aircraft-based instruments to build a common remote sensing based toolkit for city management. It would provide high resolution morphology and land characteristics of the target cities (initially Phoenix, Houston, Atlanta, and Baltimore). The results of this effort will be valuable data that can be used to improve existing urban models, and also to develop new ones to attain more accurate results.

National Institutes of Health (NIH)

The NIH (under the Department of Health and Human Services) is another long term coordination opportunity to explore health impacts of the improvements in urban air quality that may result from UHI mitigation at the urban and global levels. DOE could partner with NIH to study the air quality and resultant resident health impacts of large scale albedo modification projects.

National Climate Service

In early 2010, the current administration announced plans to form a National Climate Service (under the current National Oceanic and Atmospheric Administration) that will provide climate science, data, information, and services, and should be functionally operating before the spring of 2011. Such a service would have valuable data and access to resources that can greatly aid the research community in exploring modeling and benefits of albedo modification at the urban level.

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8 UNADDRESSED OPPORTUNITIES

The following are currently unaddressed opportunities that may warrant funding in the future, depending on needs and developments regarding cool roofs, surfaces, and urban heat island mitigation.

Cool Roofs Durability Study

The long term durability of cool roof products is unknown. They are believed to last longer than non-cool roof products, but their durability is uncertain. DOE may look to work with industry to evaluate the expected life of cool roofs compared with their darker colored counterparts, but the study will require a large cost share.

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Appendix A: Status of Cool Roof Requirements in National Building Codes

Standard	Building Type (Residential, Commercial, Federal)	Status (Code, Proposal, Policy, Program)	Description	Cool Roof Minimum Requirements SR = Solar Reflectance TE = Thermal Emittance SRI = Solar Reflectance Index
ASHRAE 90.1-2007	Commercial	Code	Both prescriptive and performance compliance. Prescriptive pathway: If a building has a cool roof, it can meet lower insulation thermal resistance requirements. Applicable only in climate zones 1-3.	SR=0.70 and TE=0.75; or SRI=82
ASHRAE 90.1-2010	Commercial	Proposal	Cool roofs will be required in climate zones 1-3 without any allowed reduction in roof insulation, but with several exceptions (e.g. asphaltic products allowed everywhere north of Miami).	**Low-slope above conditioned spaces**: aged SR=0.55 and aged TE=0.75 or aged SRI=64 or initial SR=0.70 and initial TE=0.75 or initial SRI 82
ASHRAE 90.2-2007	Residential	Code	Permits both prescriptive and performance compliance. Two forms of credits for cool roofs. Prescriptive compliance allows reduced insulation thermal resistance.	SR=0.65 and TE=0.75; or SRI=75
2009 IECC	Commercial & Residential	Code	Explicitly offers cool roof credits for residential buildings through performance compliance. Provision allowing commercial buildings to comply by satisfying requirements of ASHRAE 90.1 (cool roof credits).	**Residential**: SR=0.25 and TE=0.90; **Commercial**: References ASHRAE 90.1 as compliance pathway: SR=0.70 and TE=0.75; or SRI=82
2012 IECC	Commercial & Residential	Proposal	Will require cool roofs in climate zones 1-3 without reduced insulation thermal resistance, with few exceptions.	**Low-slope above conditioned spaces**: aged SR=0.55 and aged TE=0.75 or aged SRI=64 or initial SR=0.70 and initial TE=0.75 or initial SRI 82
ASHRAE 189.1-2009	Mostly Commercial	Code	Advanced building code for commercial and high rise residential. Designed to be adopted in place of ASHRAE 90.1 or IECC. Mitigation of heat island effect through required cool roofs in climate zones 1-3.	**Low-slope** initial SRI=78; **Steep-slope** initial SRI=29 Or comply with ENERGY STAR roof product eligibility criteria
IGCC	Commercial & Residential	Code	Cool roofs in climate zones 1-3. References ASHRAE 189.1 as an additional jurisdictional option. All roof products tested per CRRC-1.	**Low-slope** aged SR=0.55 and aged TE=0.75; or aged SRI=60; **Steep-slope** aged SR=0.30 and aged TE=0.75; or aged SRI=25
10CFR433	Federal Commercial	Code	References ASHRAE 90.1-2004 as baseline. Both prescriptive and performance compliance pathways.	References ASHRAE 90.1-2004: Prescriptive pathway- initial SR=0.70 and TE=0.75
10CFR435	Federal Residential	Code	References 2004 IECC Supplement (to 2003 IECC) as baseline. 2004 Supplement did not include mention of cool roofs.	2003 IECC has neither direct nor indirect cool roof credits for residential buildings

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DOE-wide Cool Roof Policy	Federal	Policy	Replacements and new construction shall be cool roofs, unless deemed uneconomical by life cycle analysis.	**Low-slope** aged SR=0.55 and aged TE=0.75; or aged SRI=64; **Steep-slope** aged SRI=29
ENERGY STAR	Commercial & Residential	Program	Voluntary program. For products to be listed by ENERGY STAR, they must meet minimum requirements for initial and aged SR and TE values.	**Low-slope** initial SR=0.65, aged SR=0.50; **Steep-slope** initial SR=0.25, aged SR=0.15

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