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April 17, 2003

To: Chris Scruton (CEC)  
From: Steve Wiel  
Subject: **Cool Roof Colored Materials:** Quarterly Progress Report for First Quarter 2003  
CC: Hashem Akbari, Paul Berdahl, Andre Desjarlais, Bill Miller, Ronnen Levinson

A summary of the status of Tasks and Deliverables as of March 31, 2003 is presented in Attachment 1.

### HIGHLIGHTS

- The second project advisory committee (PAC) meeting was held through a conference call on March 11, 2003.
- The project team visited the ISP Mineral Corporation's granule manufacturing plant in Ione, CA.
- The project team visited the Elk Corporation's shingle manufacturing plant in Shafter, CA.
- Mike Evans Construction and the Sacramento Municipal Utility District (SMUD) have agreed to participate in the demonstration of cool roof products. Of the sights evaluated, we decided to proceed to monitor homes in Cavalli Hills, a subdivision that Evans is building in Sacramento.
- We made significant new theoretical and computational progress in our characterization of the optical properties of pigments.

### Tasks

- 1.1 Attend Kick-Off Meeting  
**This Task is completed.**
- 1.2 Describe Synergistic Projects  
**This Task is completed.**
- 2.1 Establish the Project Advisory Committee (PAC)  
*This task is essentially completed. We have added two new members to the PAC.*

2.2 Software Standardization  
(No activity.)

2.3 PAC Meetings

We held our second PAC meeting on March 11, 2003, through a conference call. The agenda for the PAC meeting, the minutes of the meeting, the list of attendants, and the presentation material for the PAC meeting is available at <http://eden.lbl.gov/hashem/share/2003-03-11-mtg-min1-HA.pdf>.

2.4 Development of Cool Colored Coatings

2.4.1 Identify and Characterize Pigments with High Solar Reflectance

**A.** We have characterized 58 pigments so far. The basic characterization consists of spectral reflectance of a coating containing the pigment, backed with white and black coatings, and with no backing. Also measured is the spectral transmittance of the coating. Then, computer software (read on) is employed to extract scattering power  $S$  and absorption power  $K$  at each wavelength across the solar spectrum.

We continued to advance our theory for the determination of pigment properties (scattering coefficient  $S$  and absorption coefficient  $K$ ) from measurements of paint film reflectance and transmittance. Specifically, we have developed a variation on the standard Kubelka-Munk model that keeps track of beam "diffuseness", or extent to which an incident collimated light beam (such as that generated by a photo-spectrometer) has been diffused by passage through a paint film. The diffuseness is needed to accurately correct measured film reflectances and transmittances for the effects of refractive-index changes at boundaries (e.g., air-film interfaces). Our model relates the diffuseness to the  $K$  and  $S$  in a manner that may allow us to compute the three unknowns (diffuseness,  $K$ , and  $S$ ) from one reflectance measurement and one transmittance measurement.

We continue to make a number of significant improvements/changes to our pigment-property calculations. These improvements mostly relate to the details of the angular distribution of radiant energy inside the pigment-filled coating and the estimation of the reflectances at various interfaces. More details can be found in the monthly reports.

**B.** We continue to draft a journal paper reporting our pigment-characterization results to date.

**C.** We bought an inexpensive roller mill that will be used (a) to form paints from the dry pigments supplied by our industrial partners, and (b) to mix paints. The roller mill spins a jar (containing pigment, water, binder, and grinding media if dispersing pigment into a binder, or several paints and grinding media if mixing paints) on a pair of rollers.

**D.** We had discussions with Shepherd Color, Ferro, BASF and others concerning the identification of various pigments. The discussion indicated that this is a sensitive issue. For good characterization work, it is desirable to accurately identify each individual pigment by manufacturer and product number. On the other hand, some companies don't want the pigment characterization work to produce a catalog that customers use to select products. We will need eventually to come to consensus with the companies on a suitable format for publishing our characterization data.

E. We tested some commercial cool materials, silicon solar panels, and NTT-AT (NTT-Advanced Technology) cool colors. NTT is a large Japanese telecommunications company.

The amorphous silicon photovoltaic panels (Uni-solar, Ovonic) are examples of cool dark roofing. These panels were bluish-black, with visible reflectance of about 7%. They have an elevated reflectance in the infrared, with overall solar reflectance (direct + diffuse) of 25%. Thus the solar absorptance is only 75% (low for a dark material). Furthermore, about 6% of the absorbed energy can be converted to electricity, reducing the effective solar absorptance to 69%.

We also tested two samples of NTT-AT cool dark materials, a green and a brown. The spectral reflectance curves appear different from those measured so far. This is a two-coat system, with a white undercoat. The reflectance is 0.26 for green and 0.35 for brown.

#### 2.4.2 Develop a Computer Program for Optimal Design of Cool Coatings

The algorithms being developed under Task 2.4.1 will be used in this task. We have created the basic software for predicting the performance of layered paint films, and employed it to validate computed values of  $K$  and  $S$ . That is, we use values of  $K$  and  $S$  computed from the measured reflectance and transmittance of a paint film over a void (that is, with a black body cavity background) to compute the reflectances of the same paint film over both white and black backgrounds. We then compare predicted to measured reflectances. The software will be extended to handle the case of paint mixtures.

#### 2.4.3 Develop a Database of Cool-Colored Pigments (No activity.)

#### 2.5 Development of Prototype Cool-Colored Roofing Materials

##### 2.5.1 Review of Roofing Materials Manufacturing Methods

On March 12, Levinson, and Akbari visited the ISP Mineral Corporation's granule plant at Ione, CA. Dr. Ingo Joedicke (ISP Mineral Head Quarter) arranged this visit. Mr. Dave Carlson, the plant manager at Ione, gave us a complete tour of the facilities from the rock quarries to final production of colored shingle granules. During the visit, we learned that it is feasible to manufacture novel cool-colored granules through a two-layer coating approach.

On February 19, Berdahl, Levinson, and Akbari visited the Elk Corporation's asphalt shingle factory in Shafter, CA. Lou Hahn (from Elk) and Chris Gross (from 3M) accompanied us on this visit. During the visit, we learned that very little of the black asphalt substrate (typically only a few percent) is permitted to show through the granule layer. This confirms our approach that the most effective way for designing cool shingles is to increase the reflectance of granules.

In these visits, it appeared that the existing equipment for measuring the color of shingles may need to be expanded to afford capabilities for measuring reflectance in the near-infrared or solar spectra.

##### 2.5.2 Design Innovative Methods for Application of Cool Coatings to Roofing Materials

We prepared samples for the testing and analysis of the two-layer technique for applying cool pigments on roofing materials. The near-infrared (NIR) reflectance of a NIR-

transparent paint film can be raised through use of a NIR-reflective undercoat. We have prepared samples of various NIR-reflective undercoats, including white paints with high concentrations of titanium dioxide, metal paints based on aluminum flakes, and mica-flake paints. We have found that even fairly thin layers of white paint can be made NIR reflective if the pigment concentration is high. The NIR reflectance of aluminum-flake paints (about 0.6) was significantly lower than that of aluminum foil (about 0.9), suggesting either that the binder or the flakes were more absorptive than expected. The NIR reflectance of the mica-flake paints was comparable to the aluminum-flake paints.

### 2.5.3 Accelerated Weathering Testing

(No activity.)

### 2.6 Field-Testing and Product Useful Life Testing

Mike Evans of Evans Construction has agreed to work and cooperate with us (ORNL), the Sacramento Municipal Utility District (SMUD), and Hanson Roof Tile for setting up two concrete tile roofs on residential homes located in a Sacramento subdivision. Custom-Bilt Metals and Classic Products have also agreed to supply painted metal roof products for two residential homes adjacent the tile roofs.

Hanson Tile shipped its Portland cement and sand mixture to Ferro Corp. to blend a color in advance of fabricating the roof test materials. Todd Miller of Classic Products forwarded to Evans brochures of painted metal singles and shakes. Evans commented that he liked the selection of metal roof products.

MCA has made and shipped clay tile samples to ORNL for measurement of reflectance and emittance. The William Harrison Corporation is building the exposure rack sets, and will ship the racks complete with assembly instructions to the respective participating roofing manufacturers. BASF and Monier LifeTile are behind schedule for delivery of the painted metal and concrete tile samples. Coordination here is a critical path item, because ORNL must first receive these samples, measure reflectance and emittance of all the samples, place the samples in the "sure-grip" sub-assemblies and forward them to the respective sites for the start of exposure testing.

Land use agreements were granted for setup of the exposure rack sets in seven sites across the state of California.

#### 2.6.1 Building Energy-Use Measurements at California Demonstration Sites

The SMUD and ORNL have agreed to work together to instrument the demonstration homes and have developed a common data acquisition system (DAS) for measuring wall, roof and HVAC performance (see Table 1 of Attachment). SMUD has agreed to conduct routine maintenance of the DAS systems. We (ORNL) will install all instruments with exception of the watt-hour meters, which SMUD will install to measure total and HVAC power draws for each house.

ORNL and LBNL have selected Cavalli Hills, a new subdivision being built within the city limits of Sacramento, CA for demonstrating cool roof color materials in tile and painted metals. Cavalli Hills is located about a 30-minute drive east of the CEC headquarters. This is an excellent opportunity for demonstrating the energy benefits of cool roof color materials on residential roofs because of Cavalli Hills close proximity to the California Energy Commission and because the homes are typical of new house construction in CA.

A Memorandum of Understanding (MOU) was signed by Evans Construction and submitted to the Sacramento Municipal Utility District (SMUD) for their approval for the setup and maintenance of data acquisition systems and instruments to be installed in the demonstration homes.

#### 2.6.2 Materials Testing at Weathering Farms in California

Kent Frame of the California Department of Water Resources approved a MOU for the placement and maintenance requirements of exposure rack sets placed in the vicinity of CIMIS sites in Shasta and Imperial counties.

The exposure rack sets are on order and will be shipped May 03 with assembly instructions to exposure sites in CA. Custom-Bilt, Steelscape, BASF, MCA and ELK will install the exposure rack sets at their facilities. ORNL personnel will install the two sets shipped to the California Irrigation Management Information System (CIMIS) sites located in Shasta and Imperial counties. Each exposure rack set is divided into three mainframe sections having respective slopes of 2-, 4- and 8-in of rise for 12-in of run. Each main frame will support two "Sure Grip" sub-frame assemblies. The "Sure Grip" assemblies are easily installed and removed from a main frame, and each assembly will support 5 rows of samples with each row holding up to 10 samples. Therefore, the exposure rack sets will have sufficient room for additional asphalt shingles and wood shake samples when they are ready for exposure testing. All samples will be no larger than 3.5-in by 3.5-in, a size that LBNL's Perkin-Elmer Lambda 900 spectrophotometer can easily accommodate.

ORNL received clay tile samples from MCA. MonierLife Tile will supply the cement tile samples. For surface consistency and ease of reflectance measurements, MonierLife will use flat concrete tiles to make their samples. BASF has agreed to supply all the painted metal samples, and sent painted metal chips to Shepherd Color Company, MonierLife Tile and MCA for selecting similar colors as compared to the painted metal samples. Shepherd Color Company and Jerry Vandewater of MonierLife Tile will work together to develop the different color CRCM tile samples.

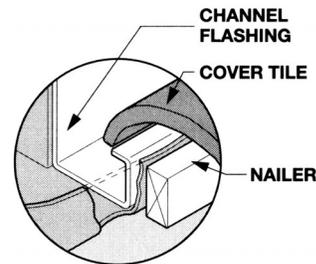
During the Project Advisory Committee meeting held on March 11, 2003, Mike Rothenberg of the Bay Area Air Quality Management District raised the question about the criteria used for selecting the exposure sites and why two sites (Colton and Corona) were selected so close to one another. W. Miller spoke later with Mike Rothenberg on Friday March 14 and stated that site selection was based on climate, local energy usage, existing population sectors and expanding population. We also wanted to involve the respective roof manufacturers in CA. Efforts were made to locate a field site near San Diego or Palm Springs; however, no roof manufacturers have plants that far south. Rothenberg liked the idea of a site near San Diego, and stated he would try to find a site through the electric public utilities.

#### 2.6.3 Steep-slope Assembly Testing at ORNL

Miller attended the Cool Metal Roofing Coalition (CMRC) meeting in January, 03 and finalized the agreement with the metal roof participants to use the existing steep-slope assembly for testing clay, tile and painted metal roofs having CRCM. The Roof Tile Institute (RTI) wants ORNL to measure the cool roof properties of five different tile assemblies that includes high profile "S" mission installed directly to the deck and over a

batten and flat concrete tiles installed over a counter batten. ORNL made a commitment to test two metal roofs, one with and one without CRCM. We will, therefore, add two additional test lanes onto the existing assembly to accommodate testing of the painted metal materials. The painted metals will be direct nailed to the roof deck.

The configuration of concrete and clay tiles and painted metals selected for testing on the steep-slope assembly of the ERSA was reviewed with Jerry Vandewater of Monier Lifetile. All tiles whether direct nailed or installed on battens will have a venting occurring up along the height and transversely along the width of the test roofs. The Roof Tile Institute (RTI) had advised using a bead of foam between lanes to allow transverse venting effects only within a given test roof and not between test roofs. After further discussion however, we decided to use a parapet partition with channel flashing (see figure) between each test roofs to eliminate any effects of transverse airflow from one test roof to another.



RTI is keenly interested in better understanding the effects of venting between the roof deck and the clay and concrete tiles. The convection heat transfer in this space may be mixed, and is an important environmental heat transfer problem that can affect thermal performance of the roof. The mixed convection flow poses significant reductions in heat transfer penetrating the roof depending on whether the thermal buoyancy force is assisting or opposing the forced flow. Dr. Majid Keyhani and graduate students in the Mechanical Engineering Department of the University of Tennessee are working with W. Miller to develop a mathematical approach for numerically solving the Navier-Stokes and energy equation and validating the approach against a well-controlled laboratory experiment and also against the field data acquired from the ESRA and the demonstration homes in Sacramento, CA.

Computer simulations were conducted to better understand the effects of the air gap between a roof deck and clay or concrete tiles. This study was conducted to view the heat transfer dynamics within thin channels that are present in some steep-slope roofing systems. Parker, Sonne and Sherwin (2002) demonstrated that white barrel and white flat tiles reduced cooling energy consumption by 22% of the base load used by an adjacent and identical home having direct nailed dark shingles. Part of the savings was due to the reflectance of the white tiles; however, another part may be due to the natural convection occurring within the counter-batten installation. Here wood furring strips are laid vertically (soffit-to-ridge) against the roof deck, and a second, counter-batten is laid horizontally across the vertical battens as a nailing surface for the concrete tile. The presence of the air space created by the counter-batten installation offers a unique improvement in the insulating effect of the roofing system.

Computations were run for several flow geometries and boundary conditions with the goal of shedding qualitative light on the dynamics of airflow in inclined ducts heated from the top surface. We modeled vented 2-D laminar airflow with convective heat transfer through a narrow channel, 0.1-m high and 2-m long, at various angles of inclination. The top and bottom surfaces were isothermal, and the left and right surfaces

left open. The bottom deck surface was set at 20°C and the top roof surface was held at a constant  $\Delta T$  with respect to the bottom surface. The channel slopes up toward the right for inclination angles  $> 0^\circ$ . Airflow dynamics were modeled for four conditions:

- a.  $0^\circ$  inclination       $15^\circ\text{C } \Delta T$ ,
- b.  $5^\circ$  inclination       $15^\circ\text{C } \Delta T$ ,
- c.  $30^\circ$  inclination       $15^\circ\text{C } \Delta T$ , and
- d.  $5^\circ$  inclination       $21^\circ\text{C } \Delta T$ .

Results of the computational analysis showed that with no inclination, natural convection flow developed in an expected manner with a plume forming above the heated surface and no net flow observed within the channel regardless of the  $\Delta T$  through the duct. With  $5^\circ$  of inclination, there was observed a distinct flow into the duct at the bottom and out of the duct at the top. At a slope of  $30^\circ$  the same flow patterns were seen, but the exit jet showed a greater exit velocity.

Case “d” is of particular interest because with an inclination of  $5^\circ$  and a top surface of only  $21^\circ\text{C}$ , the same flow characteristics occur as observed for case “b” having the  $15^\circ\text{C } \Delta T$ . These simulations indicated that naturally induced flow could be expected at very low inclination angles and very low temperature differences.

The buoyancy induced flow carries heat away from the duct. However, these preliminary results do not take into account the effect of a forced flow component, which may aid or oppose the naturally induced flow. That work, and a formal study of the heat transfer effects of the associated flows are under current exploration.

#### 2.6.4 Product Useful Life Testing (No activity.)

#### 2.7 Technology transfer and market plan

##### 2.7.1 Technology Transfer

John Lund of Ferro Corporation, on behalf of ORNL, presented the paper “PVDF Coatings with Special IR Reflective Pigments” at the Fluorine in Coatings V conference held in Orlando, FL on January 21, 2003. The Paint Research Association (PRA) International Center for Coatings Technology hosted the conference. The presentation addressed the physics of CRCM in boosting reflectance and highlighted the fade resistance for two-years of weathering of complex inorganic color pigments used in painted polyvinylidene fluoride coatings applied to painted metal.

##### 2.7.2 Market Plan (No activity.)

##### 2.7.3 Title 24 Code Revisions

Akbari and CEC discussed the details of the code language for application of reflective low-sloped on non-residential buildings.

#### **Management Issues**

- None

Attachment 1

**Project Tasks and Schedules (Approved on May 16, 2002)**

Task	Task Title and Deliverables	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 03/31/2003
1	<b>Preliminary Activities</b>					
1.1	Attend Kick Off Meeting <i>Deliverables:</i> <ul style="list-style-type: none"> <li>Written documentation of meeting agreements and all pertinent information (<b>Completed</b>)</li> <li>Initial schedule for the Project Advisory Committee meetings (<b>Completed</b>)</li> <li>Initial schedule for the Critical Project Reviews (<b>Completed</b>)</li> </ul>	5/16/02	5/16/02	6/1/02	6/10/02	100%
1.2	Describe Synergistic Projects <i>Deliverables:</i> <ul style="list-style-type: none"> <li>A list of relevant on-going projects at LBNL and ORNL (<b>Completed</b>)</li> </ul>	5/1/02	2/1/02	5/1/02	5/1/02	100%
1.3	Identify Required Permits	N/A		N/A		
1.4	Obtain Required Permits	N/A		N/A		
1.5	Prepare Production Readiness Plan	N/A		N/A		
2	<b>Technical Tasks</b>					
2.1	Establish the project advisory committee <i>Deliverables:</i> <ul style="list-style-type: none"> <li>Proposed Initial PAC Organization Membership List (<b>Completed</b>)</li> <li>Final Initial PAC Organization Membership List</li> <li>PAC Meeting Schedule (<b>Completed</b>)</li> <li>Letters of Acceptance</li> </ul>	6/1/02	5/17/02	9/1/02		100%
2.2	Software standardization <i>Deliverables:</i> <ul style="list-style-type: none"> <li>When applicable, all reports shall include additional file formats that will be necessary to transfer deliverables to the CEC</li> <li>When applicable, all reports shall include lists of the computer platforms, operating systems and software required to review upcoming software deliverables</li> </ul>	N/A		N/A		

## Project Tasks and Schedules (contd.)

Task	Task Title and Deliverables	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 03/31/2003
2.3	PAC meetings <i>Deliverables:</i> <ul style="list-style-type: none"> <li>Draft PAC meeting agenda(s) with back-up materials for agenda items</li> <li>Final PAC meeting agenda(s) with back-up materials for agenda items</li> <li>Schedule of Critical Project Reviews</li> <li>Draft PAC Meeting Summaries</li> <li>Final PAC Meeting Summaries</li> </ul>	9/1/02	6/1/02	6/1/05		33% (2/6)
2.4	Development of cool colored coatings					
2.4.1	Identify and Characterize Pigments with High Solar Reflectance <i>Deliverables:</i> <ul style="list-style-type: none"> <li>Pigment Characterization Data Report</li> </ul>	6/1/02	6/1/02	12/1/04		~30%
2.4.2	Develop a Computer Program for Optimal Design of Cool Coatings <i>Deliverables:</i> <ul style="list-style-type: none"> <li>Computer Program</li> </ul>	11/1/03		12/1/04		
2.4.3	Develop a Database of Cool-Colored Pigments <i>Deliverables:</i> <ul style="list-style-type: none"> <li>Electronic-format Pigment Database</li> </ul>	6/1/03		6/1/05		
2.5	Development of prototype cool-colored roofing materials					
2.5.1	Review of Roofing Materials Manufacturing Methods <i>Deliverables:</i> <ul style="list-style-type: none"> <li>Methods of Fabrication and Coloring Report</li> </ul>	6/1/02	6/1/02	6/1/03		~55%
2.5.2	Design Innovative Methods for Application of Cool Coatings to Roofing Materials <i>Deliverables:</i> <ul style="list-style-type: none"> <li>Summary Coating Report</li> <li>Prototype Performance Report</li> </ul>	6/1/02	6/1/02	12/1/04		< 5%
2.5.3	Accelerated Weathering Testing <i>Deliverables:</i> <ul style="list-style-type: none"> <li>Accelerated Weathering Testing Report</li> </ul>	11/1/02	10/1/02	6/1/05		< 3%

**Project Tasks and Schedules (contd.)**

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 03/31/2003
2.6	Field-testing and product useful life testing					
2.6.1	Building Energy-Use Measurements at California Demonstration Sites <i>Deliverables:</i> <ul style="list-style-type: none"> <li>• Demonstration Site Test Plan</li> <li>• Test Site Report</li> </ul>	6/1/02	9/1/02	10/1/05		7%
2.6.2	Materials Testing at Weathering Farms in California <i>Deliverables:</i> <ul style="list-style-type: none"> <li>• Weathering Studies Report</li> </ul>	6/1/02	10/1/02	10/1/05		15%
2.6.3	Steep-slope Assembly Testing at ORNL <i>Deliverables:</i> <ul style="list-style-type: none"> <li>• Whole-Building Energy Model Validation Presentation at the Pacific Coast Builders Conference</li> </ul>	6/1/02	10/1/02	10/1/05		14%
2.6.4	Product Useful Life Testing <i>Deliverables:</i> <ul style="list-style-type: none"> <li>• Solar Reflectance Test Report</li> </ul>	5/1/04		6/1/05		
2.7	Technology transfer and market plan					
2.7.1	Technology Transfer <i>Deliverables:</i> <ul style="list-style-type: none"> <li>• Publication of results in industry magazines and refereed journal articles</li> <li>• Participation in buildings products exhibition, such as the PCBC Brochure summarizing research results and characterizing the benefits of cool colored roofing materials</li> </ul>	6/1/03	6/1/02	6/1/05		~ 3%
2.7.2	Market Plan <i>Deliverables:</i> <ul style="list-style-type: none"> <li>• Market Plan(s)</li> </ul>	5/1/05		6/1/05		
2.7.3	Title 24 Code Revisions <i>Deliverables:</i> <ul style="list-style-type: none"> <li>• Document coordination with Cool Roofs Rating Council in monthly progress reports</li> <li>• Title 24 Database</li> </ul>	6/1/02	5/16/02	6/1/05		~ 5%

**Project Tasks and Schedules (contd.)**

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 03/31/2003
VII	Critical Project Review(s) <i>Deliverables:</i> • Minutes of the CPR meeting					
XII (C)	Monthly Progress Reports <i>Deliverables:</i> • Monthly Progress Reports	6/1/02	6/1/02	6/1/05		28% (10/36)
XII (D)	Final Report <i>Deliverables:</i> • Final Report Outline • Final Report	3/1/05		10/1/05		
	Final Meeting <i>Deliverables:</i> • Minutes of the CPR meeting	10/15/05		10/31/05		