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July 29, 2005

To: Chris Scruton (CEC)
From: Hashem Akbari
Subject: **Cool Roof Colored Materials**: Quarterly Progress Report for Spring 2005
CC: Steve Wiel, Paul Berdahl, Andre Desjarlais, Nancy Jenkins, Bill Miller, Ronnen Levinson

A summary of the status of Tasks and Deliverables as of June 30, 2005 is presented in Attachment 1.

HIGHLIGHTS

- We have completed two reports describing our development of cool nonwhite roofing material prototypes. The first, "Methods of creating solar-reflective nonwhite surfaces and their application to residential roofing materials," was submitted to the journal *Solar Energy Materials & Solar Cells*. The second, "Cool roofing prototype development activities," is a brief summary of our activities. **This completes Task 2.5.2**.
- We have developed preliminary estimates of savings obtained from the installation of cool colored roofs on air conditioned houses in all California climate regions. A short report summarizing these estimates was prepared. **This completes Task 2.7.3**.
- We released a beta version of our coating formulation software ("Pinwheel: a tool for the design of color matched coatings with high solar reflectance") to our industrial partners. **This completes Task 2.4.2**.
- John McCaskill of Elk Corp., Bob Scichili, a consultant with Custom-Bilt Metals, Mark Wiebusch of Modern Trade Communications and Scott Kriner of Akzo Nobel Coatings Inc. are helping to develop a Market Plan for accelerating the penetration of cool colored roofing materials into the California market.
- LBNL, MCA Clay Tile, Elk Corporation, and Custom-Bilt Metals showcased cool colored roofing products at an exhibit of California's green energy technologies held in San Francisco's City Hall on the occasion of the United Nation's World Environment Day (June 1) and at the 8th Annual

Congressional Renewable Energy/Energy Efficiency EXPO, in Washington DC (June 21).

- The completion date for the deliverables of Tasks 2.5.3, 2.6.4, and 2.7.2 has been postponed to the end of July 2005.
- Elemental analysis of the contaminants soiling the roof samples exposed at the seven CA sites was completed and the results show that samples exposed in Richmond (San Francisco basin area) had the largest amounts of elemental carbon (about 500 ug) as compared to all other weathering sites.
- Experiments at the ORNL roof testing facilities show that the natural venting of the underside of the tile and thermal mass reduces the heat flux through the roof by 70%.

Tasks

1.1 Attend Kick-Off Meeting
Task completed.

1.2 Describe Synergistic Projects
Task completed.

2.1 Establish the Project Advisory Committee (PAC)
Task completed.

2.2 Software Standardization
(No activity.)

2.3 PAC Meetings
Task completed.

2.4 Development of Cool Colored Coatings

2.4.1 Identify and Characterize Pigments with High Solar Reflectance
Task completed.

2.4.2 Develop a Computer Program for Optimal Design of Cool Coatings
Task completed.

We created a beta version of "Pinwheel, a tool for the design of color matched coatings with high solar reflectance" our coating formulation software, and shared it with our program manager at CEC and our industrial partners. Five manufacturers are currently testing the application.

The software has been calibrated by comparing its predictions to the known compositions, visible spectral reflectances, and solar reflectance of mixtures prepared and characterized earlier in this project. We improved its performance by using absorption coefficients derived from the characterizations of tints (mixtures with white) in place of those obtained from the characterizations of masstones. The latter process tends to underestimate absorption by strongly absorbing pigments, and consequently overpredict the reflectance of mixtures containing such pigments.

2.4.3 Develop a Database of Cool-Colored Pigments
Task completed.

2.5 Development of Prototype Cool-Colored Roofing Materials

2.5.1 Review of Roofing Materials Manufacturing Methods
Task completed.

2.5.2 Design Innovative Methods for Application of Cool Coatings to Roofing Materials
Task completed.

We have completed two reports describing our development of cool nonwhite roofing material prototypes. The first, "Methods of creating solar-reflective nonwhite surfaces and their application to residential roofing materials," is a technical paper that we have submitted to the journal *Solar Energy Materials & Solar Cells*. The second, "Cool roofing prototype development activities," is a brief summary of our activities.

2.5.3 Accelerated Weathering Testing
Work on the manuscript on accelerated weathering is awaiting the completion of the manuscript of Task 2.6.4. We expect to complete this report by the end of August 2005.

Ben Simkin of Arkema, Inc. provided us with materials on the weathering of PVDF roof coatings. Work on the manuscript on accelerated weathering is awaiting the completion of the manuscript of task 2.6.4. We expect to complete this report by the end of June 2005.

2.6 Field-Testing and Product Useful Life Testing
ORNL's Environmental Science Division (ESD) completed its analysis of the contaminants soiling the roof samples pulled from the seven CA weathering sites. Dr. Susan Pfiffner continued working on the biomass analysis of similar samples. Results of the elemental analysis shows the presence of a wide spread of elements. The seven top elements having highest measured concentrations are shown in Fig. 1. Aluminum and iron are prevalent at all seven sites, with exception of McArthur. The high altitude of McArthur yields little dust and carbon soot pollution (Fig. 1). Richmond and Colton show large amounts of calcium. Elemental carbon was observed largest in Richmond, probably because of car emissions. Besides Richmond, only Shafter shows noticeable amounts of soot deposition. However on a gram-by-gram basis, small amounts of elemental carbon are about 170 times more effective as absorbers of solar irradiance than are iron oxides.

2.6.1 Building Energy-Use Measurements at California Demonstration Sites
Shingle Demonstrations: The Memorandum of Understanding (MOU) for the asphalt shingle field demonstrations was signed by Elk Corp., ORNL and by Ochoa and Shehan Inc., and copies were sent to all participants. Residents moved into their new homes demonstrating cool colored asphalt shingle roofs and the field data is online being logged at ORNL. Field data shows the cool colored shingles are about $3^{o}C$ ($5^{o}F$) cooler at solar noon than the conventional shingles. As result, the cool roof has reduced the heat flux penetrating the west facing roof by roughly 15% of that measured for the roof with conventional pigmented shingles. We have acquired about 12 weeks of field data, and continue to monitor the demonstrations in Redding, CA.

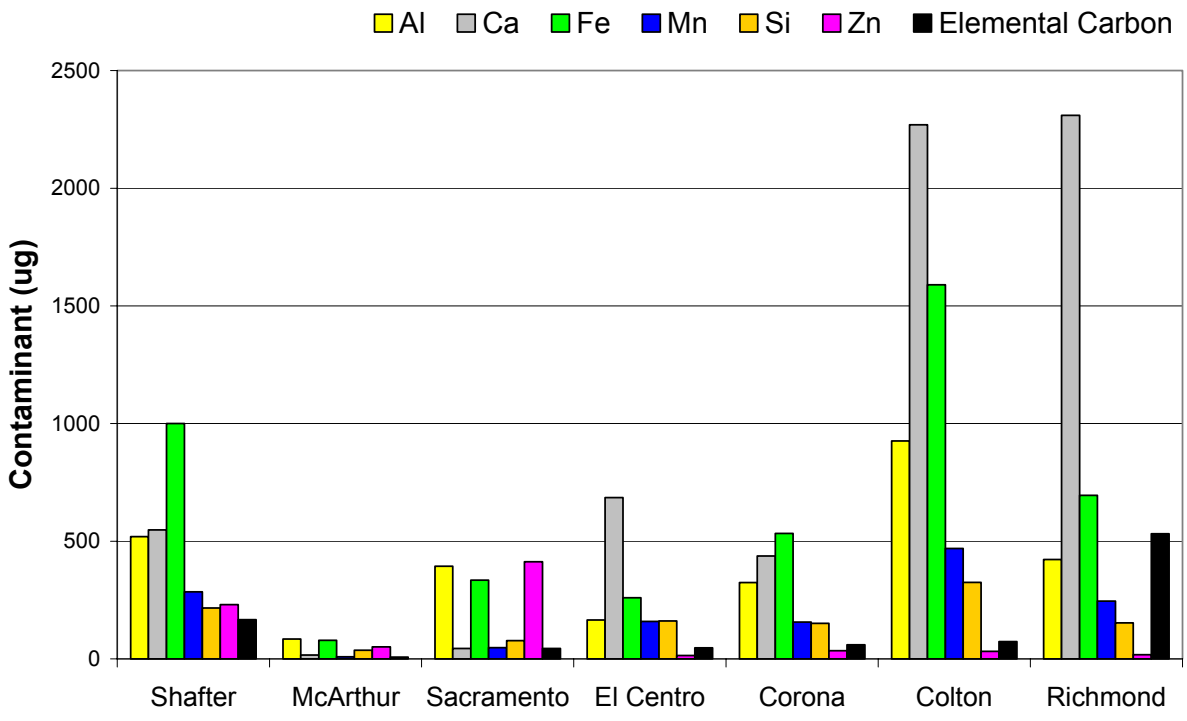

Figure 1. Major elemental contaminants measured on roof samples pulled from CA weathering sites.

Painted Metal and Concrete Demonstrations: Data for the week of May 27 through June 2, 05 shows that the all residents in Fair Oaks, CA are now air-conditioning their respective homes (Fig. 2). Previous validation work with SMUD showed the whole house power transducers measurements were within 1½ % of measurement of the utilities' watt-hour meter. The pair of homes with painted metal roofs shows a 20% reduction in whole house power for the week of data shown in Figure 2, which is due in part to the cool roof system. However, data for the pair of homes with concrete tile roofs shows the home with cool colored tile roof used 25% more power than the home with conventional tile roof. A review of the supply air and return air data shows the home with cool roofs has the thermostat set at a lower temperature than the home with the conventional tile roof.

2.6.2 Materials Testing at Weathering Farms in California

ORNL's Environmental Science Division (ESD) is in process of measuring the elemental composition of the dust collected from the roof samples exposed at the seven CA weathering sites. Dr. Susan Pfiffner is also working to complete biomass analysis of samples gathered from the weathering sites. Efforts are being made to correlate metered weathered data and contaminant concentrations to formulate an empirical correlation for the drop in solar reflectance of the roof products. The strength of the regression coefficients will help illuminate those parameters most strongly affecting the loss of solar reflectance.

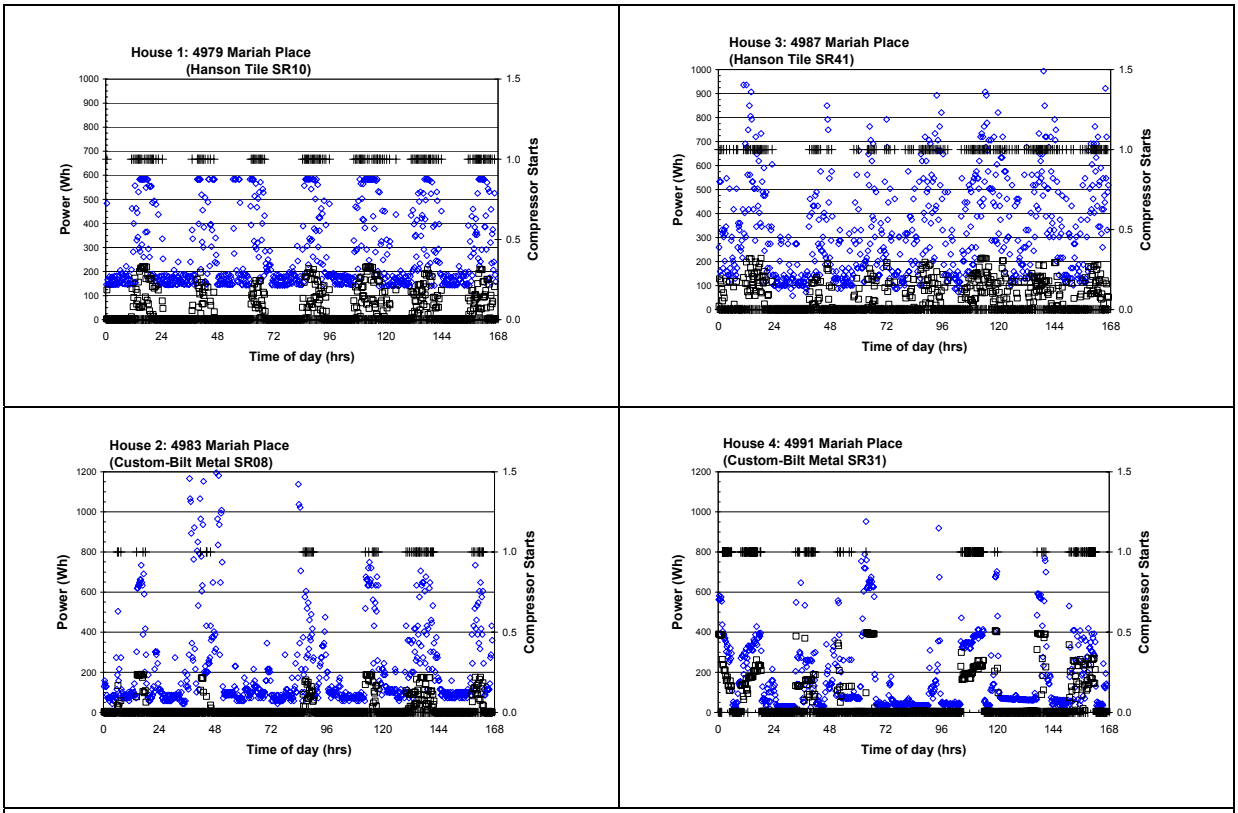

Figure 2. Whole house (◊) and compressor (□) power and compressor starts (+) measured for the two pair of demonstration homes in Fair Oaks, CA. Data collected for the week of May 27 through June 2, 2005.

2.6.3 Steep-slope Assembly Testing at ORNL

The ridge vents to the clay and concrete tile roofs and the asphalt shingle roofs were opened in May. Hence field data is now being acquired for the case where attic and underside venting of the tile occurs with the ridge vent open as compared to earlier data with the ridge vent closed. Field data for the tile roof assemblies were reduced for the months of August 04 and January 05 to view the total flux crossing the roof deck and ceiling of each attic assembly. Table 1 lists the reduced data for the day time hours in August 04 for the S-mission clay tile (SR54E90), the concrete slate tile (SR13E83) and the asphalt shingle (SR10E89) roofs.

Table 1. Thermal performance of tile roofs measured during August 04.

Roof	Roof Deck	Surface (°F) Daylight Hours		Attic Air (°F) Daylight Hours		Heat Flux (Btu/ft²) Daylight Hours	
		Average	Max	Average	Max	Ceiling	Deck
S-mission	Direct-to-Deck	91.0	135.7	79.7	99.0	242.3	1127.4
Slate	Counter Batten	100.1	154.6	81.8	106.2	466.3	2446.2
Shingle	Direct-to-Deck	101.3	162.5	86.3	115.7	1047.6	4099.4

The S-mission clay tile and asphalt shingle are direct nailed to the deck while the slate is installed on counter battens. The addition of cool colored pigments to the clay tile has

dropped the heat penetrating the roof deck by 72% of that measured for the asphalt shingle roof. The reduction is due in part to the cool pigments but is also due to the venting occurring along the underside of the tile roof. It is very interesting that the dark slate tile (SR13E83) as compared to the shingle roof (SR10E89) reduced the deck heat flow by 40%, which clearly shows the benefit derived from venting the roof deck. Proportioning the percentage drops based on the integrated day time loads (i.e., ~40% reduction for the SR13E83 and a 72% drop for the SR54E90 tile as compared to the shingle roof), to the difference in solar reflectance for the clay tile (SR54E90) and the asphalt shingle (SR10E90) yields about 25 points of solar reflectance.

$$\overbrace{\frac{40\%\ \text{due to venting}}{72\%\ \text{due to venting and SR}}}^{\text{heat reduction}} \cdot \left[SR54_{\text{Clay Tile}} - SR10_{\text{Shingle}}\right]$$

Therefore venting the deck credits the dark slate tile with an addition 25 points of solar reflectance. It is difficult to judge whether venting or surface reflectance is the predominant force dropping the roof flux. However, Beal and Chandra (1995) showed that S-mission tile on battens reduced the heat penetrating the ceiling an additional 11% as compared to the same tile of the same color direct-nailed to the deck.

Data for the month of January 05 show that the thermal mass of the tile roofs nearly counter balances the heating penalty associated with cool roofing for the moderate climate of TN. Again venting the underside of the tile plays a part in the results (Fig. 3).

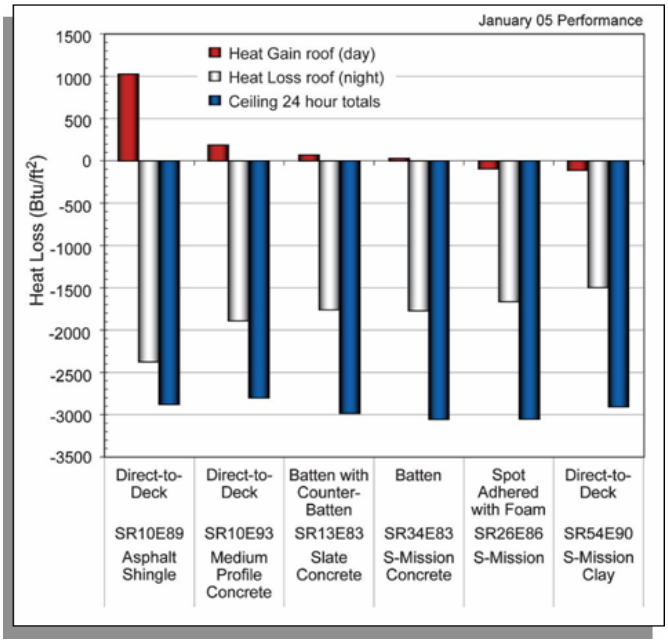

Figure 3. Heat flow measured for all tile and shingle roofs during the month of JAN 05.

The asphalt shingle roof gains about 1000 Btu per square foot of roof deck during all January days while the tile roofs show little gain and some a loss of heat from the roof

deck. However, during the evening hours the thermal mass and possibly the tile's air gap have reduced the heat loss from the roof to the point that the heat loss from the ceiling of all roofs is about the same (see blue bars Fig. 3). These data are very promising because the tile roofs are negating the heating penalty associated with a cool roof in the moderate climate of East Tennessee having 3662 HDD_{65} and 1366 CDD_{65}.

AtticSim Model: Efforts are proceeding to measure the airflow rate under the S-Mission clay tile and concrete slate tiles exposed on the Envelope Systems Research Apparatus. A procedure was developed based on tracer gas techniques outlined in ASTM E 741 and also by Lagus et al. 1988, which requires monitoring the decay rate of the tracer gas CO_2 with time. Results will be used to help validate predictions calculated by the attic model AtticSim, which in turn will predict the heat penetrating the roof deck and the heat swept by thermal buoyancy toward the ridge vent.

Various heat transfer correlations were tested against the experimental data for the S-Mission clay and concrete slate tile roofs to determine which correlations reasonably predict temperature and heat flow in the air cavity on the underside of the tile roofs. The correlation formulated by Brinkworth (2000) and McAdams (1954) were found to predict the heat flow across the roof deck within 15% of measures acquired from the deck heat flux transducers. The results are promising and we will therefore use Brinkworth's correlation among others in an algorithm formulated in AtticSim to predict heat flow through concrete and clay tile having an air gap on the underside of the tile.

Beal, D. and S. Chandra. 1995. "The measured summer performance of tile roof systems and attic ventilation strategies in hot, humid climates." In Thermal Performance of the Exterior Envelopes of Buildings, VI. Atlanta: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

Brinkworth, B. J. 2000. "A Procedure for the Routine Calculation of Laminar Free and Mixed Convection in Inclined Ducts." International Journal of Heat and Fluid Flow, v 21, p. 456-462.

McAdams, W. H., Heat Transmission, 3rd ed., McGraw-Hill, New York, 1954, Chap. 7.

2.6.4 Product Useful Life Testing

We are currently writing an overview review article on weathering of roofing. The article lists the various physical, chemical, and biological stresses on roofing materials and discusses how manufacturers tailor their manufacturing processes to manage these stresses. The effects of photo-oxidation and the effects of elevated temperatures on roofing materials are featured. Completion of this article is projected in July.

The Shepherd Color Company and 3M Mineral have received all roof samples planned for accelerated testing. Both companies started testing in May. Shepherd is exposing samples to accelerated fluorescent light while 3M Mineral is using Xenon-arc exposure. The accelerated exposure testing includes samples with and without cool-pigmented colors. The materials being tested are painted metal samples, clay tile samples, concrete tiles with American Rooftile coating and four cool prototype shingles. The painted metal, clay tile and concrete tile with coatings are already under natural exposure testing at the seven California weathering sites. A second shingle manufacturer has agreed to provide both fluorescent and Xenon-arc test data. However, he preferred to not provide prototype shingles for testing at Shepherd or 3M Mineral. He would rather his company conduct the testing. Therefore, to foster cooperation while protecting product identity, the four shingles being tested at Shepherd and 3M Mineral have been assigned codes. The data from the second shingle manufacturer will also be similarly coded.

2.7 Technology transfer and market plan

2.7.1 Technology Transfer

LBNL, MCA Clay Tile, Elk Corporation, and Custom-Bilt Metals showcased cool colored roofing products at an exhibit of California's green energy technologies held in San Francisco's City Hall on the occasion of the United Nation's World Environment Day (June 1). Levinson explained and demonstrated the performance of cool colored roofing to California Governor Arnold Schwarzenneger and several visiting mayors. An image of the Governor measuring the temperatures of color-matched cool and conventional metal roofing was distributed worldwide by the Associated Press (http://abcnews.go.com/US/wireStory?id=812675); a full-size version is online at http://CoolColors.LBL.gov

LBNL, Elk Corporation, and Custom-Bilt Metals showcased cool colored roofing products at the 8th Annual Congressional Renewable Energy/Energy Efficiency EXPO - June 21, 2005, in Washington DC. Akbari explained and demonstrated the performance of cool colored roofing to distinguished visitors including the Under Secretary for Energy, Science & Environment of DOE David Garman, Congresswoman from Berkeley Barbara Lee, and many congressman staff and assistances.

W. Miller and A. Desjarlais met with Scichili and Mark Wiebusch of Modern Trade Communications to formulate various strategies for centering attention on the painted metal “Cool Roof” initiative. Wiebusch stated that 67% of all metal building construction was done by design-build firms and that at least 50% of all metal roofs were specified by architects. Wiebusch and Scichili are planning a series of advertisements and articles that will reach about 30,000 architects subscribing to Modern Trade Communications.

Akbari gave a lecture titled “Urban Heat Islands and Mitigation Technologies: An Overview of LBNL Research,” at the Architectural Institute of Japan, Tokyo, Japan, May 31, 2005.

Akbari gave a lecture titled “Advances in Development of Cool Colored Roofing Materials,” at the Kobe University, Kobe, Japan, June 4, 2005.

Akbari gave a lecture titled “Advances in Development of Cool Colored Roofing Materials,” at the Nippon Paint Co., Ltd., Shinagawa office, Japan, June 1, 2005.

Akbari gave a lecture titled “Advances in Development of Cool Pavement Materials,” at the Sumitomo Osaka Cement Co., Kobe, Japan, June 3, 2005.

Levinson presented a talk on the design of cool nonwhite coatings at the RCI symposium Cool Roofing—Cutting Through the Glare in Atlanta on May 12.

Miller made a presentation at the RCI conference “Cutting through the Glare” on May 12- 13, 05. He presented the paper “Experimental Analysis of the Natural Convection Effects Observed within the Closed Cavity of Tile Roof Systems,” and discussed reduced data for the concrete tile roofs under field study at ORNL.

Akbari presented a paper on aging and weathering cool roofing membranes at the RCI symposium Cool Roofing—Cutting Through the Glare in Atlanta on May 12.

Akbari presented two papers titled “Potential of Urban Heat Island Mitigation” and “Cool Colored Roofs to Save Energy and Improved Air Quality” at the First International

Conference on Passive and Low Energy Cooling for the Built Environment, May 19-21, 2005, Santorini, Greece.

Akbari gave a lecture on "Urban Heat Island Mitigation" on May 23, at the University of Athens, Greece.

Akbari gave three lectures titled "Cool Colored Materials for Roofs," "Cool Surfaces and Shade Trees: To Reduce Energy Use and Improve Air Quality in Urban Areas," and "International Energy Outlook and Potentials of Energy Efficiency" at the 1st International Conference on Green Buildings: The Future in the UAE, on May 2-3, 2005, Dubai, UAE.

The National Coil Coaters Association (NCCA) invited Miller to give presentation at their annual conference held May 7 – 9 in Ft. Myers, FL. NCCA's theme for the conference is "Success through Association." Miller present results of the painted metals being demonstrated in CA.

On April 20, 2005, Akbari gave a lecture on cool colored roofing materials at the San Francisco State University.

2.7.2 Market Plan

The draft market plan was rewritten per the recommendations of several PAC members and was forwarded for final review to John McCaskill of Elk Corp., to Bob Scichili, a consultant with Custom-Bilt Metals, to Mark Wiebusch of Modern Trade Communications and to Scott Kriner of Akzo Nobel Coatings Inc. We are in the process of finalizing the document. The completion is expected by July 31, 2005.

2.7.3 Title 24 Code Revisions

Task completed.

Akbari continues working with PG&E and the Energy Commission to develop a plan for code change proposal for sloped-roof residential buildings.

We have developed preliminary estimates of savings obtained from the installation of cool colored roofs on air conditioned houses in all California climate regions.

Management Issues

- We have not yet obtained the formal approval of the requested no-cost extension (through December 2006) for the project.
- This is the last scheduled regular quarterly progress report. We will prepare one extra for summer to report the completion of four unfinished tasks (2.5.3, 2.6.4, and 2.7.2) that had been expected to be completed in spring. Since the project has been extended through December 2006 to accommodate additional testing (Tasks 2.5.3, 2.6.1, 2.6.2, 2.6.3, and 2.6.4), Akbari and Scruton will discuss options to report progress on this testing to the CEC project manager.

Attachment 1

Project Tasks and Schedules (*Approved on May 16, 2002; Revised schedules approved November 2004*)

Task	Task Title and Deliverables	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 6/30/2005
1	**Preliminary Activities**					
1.1	Attend Kick Off Meeting *Deliverables:* • Written documentation of meeting agreements and all pertinent information (**Completed**) • Initial schedule for the Project Advisory Committee meetings (**Completed**) • Initial schedule for the Critical Project Reviews (**Completed**)	5/16/02	5/16/02	6/1/02	6/10/02	100%
1.2	Describe Synergistic Projects *Deliverables:* • A list of relevant on-going projects at LBNL and ORNL (**Completed**)	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	**Technical Tasks**					
2.1	Establish the project advisory committee *Deliverables:* • Proposed Initial PAC Organization Membership List (**Completed**) • Finalize Initial PAC Organization Membership List (**Completed**) • PAC Meeting Schedule (**Completed)** • Letters of Acceptance (**Completed)**	6/1/02	5/17/02	9/1/02	9/1/02	100%
2.2	Software standardization *Deliverables:* • When applicable, all reports will include additional file formats that will be necessary to transfer deliverables to the CEC • When applicable, all reports will include lists of the computer platforms, operating systems and software required to review upcoming software deliverables	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 6/30/2005
2.3	PAC meetings (**Completed)** *Deliverables:* • Draft PAC meeting agenda(s) with back-up materials for agenda items • Final PAC meeting agenda(s) with back-up materials for agenda items • Schedule of Critical Project Reviews Draft PAC Meeting Summaries • Final PAC Meeting Summaries	9/1/02	6/1/02	6/1/05		100% (6/6)
2.4	Development of cool colored coatings					
2.4.1	Identify and Characterize Pigments with High Solar Reflectance *Deliverables:* • Pigment Characterization Data Report (**Completed)**	6/1/02	6/1/02	12/1/04 → 12/31/04	12/31/04	100%
2.4.2	Develop a Computer Program for Optimal Design of Cool Coatings *Deliverables:* • Computer Program (**Completed)**	11/1/03	11/1/03	12/1/04 → 5/1/05	5/30/05	100%
2.4.3	Develop a Database of Cool-Colored Pigments *Deliverables:* • Electronic-format Pigment Database (**Completed)**	6/1/03	7/1/03	6/1/05 → 12/31/04	12/31/04	100%
2.5	Development of prototype cool-colored roofing materials					
2.5.1	Review of Roofing Materials Manufacturing Methods *Deliverables:* • Methods of Fabrication and Coloring Report (**Completed)**	6/1/02	6/1/02	6/1/03	4/1/05	100%
2.5.2	Design Innovative Methods for Application of Cool Coatings to Roofing Materials *Deliverables:* • Summary Coating Report **(Completed)** • Prototype Performance Report **(Completed)**	6/1/02	6/1/02	12/1/04 → 5/1/05	6/30/05	~ 100%
2.5.3	Accelerated Weathering Testing *Deliverables:* • Accelerated Weathering Testing Report	11/1/02	10/1/02	6/1/05 → 10/1/05		~ 60%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 6/30/2005
2.6	Field-testing and product useful life testing					
2.6.1	Building Energy-Use Measurements at California Demonstration Sites *Deliverables:* • Demonstration Site Test Plan (**Completed)** • Test Site Report	6/1/02	9/1/02	10/1/05 → 10/1/06		90%
2.6.2	Materials Testing at Weathering Farms in California *Deliverables:* • Weathering Studies Report	6/1/02	10/1/02	10/1/05 → 10/1/06		88%
2.6.3	Steep-slope Assembly Testing at ORNL *Deliverables:* • Whole-Building Energy Model Validation • Presentation at the Pacific Coast Builders Conference • Steep Slope Assembly Test Report	6/1/02	10/1/02	10/1/05		90%
2.6.4	Product Useful Life Testing *Deliverables:* • Solar Reflectance Test Report **(Draft Prepared)**	5/1/04	5/1/04	6/1/05 → 10/1/05		95%
2.7	Technology transfer and market plan					
2.7.1	Technology Transfer (**Completed)** *Deliverables:* • Publication of results in industry magazines and refereed journal articles • Participation in buildings products exhibition, such as the PCBC • Brochure summarizing research results and characterizing the benefits of cool colored roofing materials	6/1/03	6/1/02	6/1/05	6/1/05	100%
2.7.2	Market Plan *Deliverables:* • Market Plan(s) **(Draft Prepared)**	5/1/05	4/1/05	6/1/05		80%
2.7.3	Title 24 Code Revisions *Deliverables:* • Document coordination with Cool Roofs Rating Council in monthly progress reports (**Completed)** • Title 24 Database **(Completed)**	6/1/02	5/16/02	6/1/05	6/30/05	100%

Project Tasks and Schedules (contd.)

Task	Task Title	Plan Start Date	Actual Start Date	Plan Finish Date	Actual Finish Date	% Completion as of 6/30/2005
VII	Critical Project Review(s) *Deliverables:* • Minutes of the CPR meeting					
XII (C)	Monthly Progress Reports *Deliverables:* • Monthly Progress Reports (**Completed)**	6/1/02	6/1/02	6/1/05		103% (37/36)
XII (D)	Final Report *Deliverables:* • Final Report Outline • Final Report	3/1/05 → 3/31/06		10/1/05 → 10/1/06		
	Final Meeting *Deliverables:* • Minutes of the final meeting	10/15/05		10/31/05		