DEVELOPMENT OF COOL COLORED ROOFING MATERIALS

Project Advisory Committee (PAC) Meeting
A Collaborative R&D Between Industry

LBNL and ORNL

Sponsored by the California Energy Commission
(Project Manager: Chris Scruton)

March 4, 2004; Sacramento, CA
Project Goals

• Bring cool colored roofing materials to market
• Measure and document laboratory and *in-situ* performances of roofing products
• Accelerate market penetration of cool metal, tile, wood shake, and shingle products
• Measure and document improvements in the durability of roofing expected to arise from lower operating temperatures
Project Advisory Committee (PAC) Members

1. Asphalt Roofing Manufacturers Association
2. Bay Area Air Quality Management District
3. California Institute for Energy Efficiency
4. Cedar Shake and Shingle Bureau
5. Cool Metal Roofing Coalition
6. Cool Roof Rating Council
7. DuPont Titanium Technologies
8. Environmental Protection Agency (EPA)
9. EPA San Francisco Office
10. Mike Evans Construction
11. National Roofing Contractors Association
12. Pacific Gas and Electric Company (PG&E)
13. Roof Tile Institute
14. Southern California Edison Company (SCE)
Industrial Partners

- 3M
- American Roof Tile Coating
- BASF
- CertainTeed
- Custom-Bilt Metals
- Elk Manufacturing
- Ferro
- GAF
- Hanson Roof Tile
- ISP Minerals
- MCA
- Monier Lifetile
- Steelscape
- Shepherd Color
Project Team

• LBNL
  – Steve Wiel (Project Director) SWiel@LBL.gov
  – Hashem Akbari (Technical Lead) H_Akbari@LBL.gov
  – Paul Berdahl PHBerdahl@LBL.gov
  – Ronnen Levinson RMLevinson@LBL.gov

• ORNL
  – André Desjarlais (Technical Lead) yt7@ORNL.gov
  – Bill Miller wml@ornl.gov
Technical Tasks

• 2.4 Development of cool colored coatings
• 2.5 Development of prototype cool-colored roofing materials
• 2.6 Field-testing and product useful life testing
• 2.7 Technology transfer and market plan
2.4 Development of Cool Colored Coatings

• Objectives
  – Maximize solar reflectance of a color-matched pigmented coating
  – Compare performance of a coated roofing product (e.g., a shingle) to that of a simple smooth coating

• Subtasks
  – Identify and characterize pigments with high solar reflectance
  – Develop software for optimal design of cool coatings
  – Develop database of cool-colored pigments
2.4.1 Identify & Characterize Pigments w/High Solar Reflectance

- Objective: Identify and characterize pigments with high solar reflectance that can be used to develop cool-colored roofing materials
- Deliverables:
  - Pigment Characterization Data Report (paper to be submitted to journal)
- Schedule: 6/1/02 – 12/1/04
- Funds Expended 80%
Recent Pigment Characterizations

• Diluted strongly absorbing paints (iron oxide black, titanium white)
• Pigmented paint tint ladders (colors + varying amounts of white)
• Pigmented tile glaze ladders (colors in varying concentrations)
Resolving Spectral Features of Strongly Absorbing Pigments

- We diluted strongly absorbing paints such as iron oxide black to reveal spectral reflectance features.

Diluted (4% PVC) vs Original (17% PVC):
- Spectral features clear
- Spectral features saturated & noisy
Sample Paint Tint Ladder: Mixing Red Oxide with White

Reflectance

Wavelength (nm)

pure red

1 red:4 white

1 red:9 white

pure white

25µm films over black
white
tint 1:9
tint 1:4
red
Characterizing Tile Glazes Using Concentration Ladders

• Problem:
  – Firing changes color of tile glaze
  – Transparent substrates such as quartz difficult to fire with glaze (different thermal expansion rates)

• Solution:
  – Measure spectral reflectances of white tiles coated with color glazes of varying pigment concentration
Tile Glaze Concentration Ladders

Concentration

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Pigment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5%</td>
<td>blue1</td>
</tr>
<tr>
<td>1%</td>
<td>blue2</td>
</tr>
<tr>
<td>2%</td>
<td>blue3</td>
</tr>
<tr>
<td>4%</td>
<td>blue4</td>
</tr>
<tr>
<td>6%</td>
<td>yellow1</td>
</tr>
<tr>
<td></td>
<td>yellow2</td>
</tr>
<tr>
<td></td>
<td>yellow3</td>
</tr>
</tbody>
</table>
Next Steps

• Prepare and characterize mixtures
  – analyze paint tint and tile glaze ladders
  – prepare and measure nonwhite mixtures
• Share pigment characterizations with partners (ongoing)
• Establish measurement protocols
• Apply characterizations to coating design
2.4.2 Develop a Computer Program For Optimal Design of Cool Coating

• Objective: Develop software for optimal design of cool coatings used in colored roofing materials

• Deliverables:
  – Computer Program

• Schedule: 11/1/03 – 12/1/04

• Funds Expended 10%
Recent Developments in Coating Design Software

- Design software combines
  - pigment property database
  - theory of mixtures
to
  - predict spectral reflectance of paint mixtures and layers
  - optimize solar reflectance of a given color
- Tint, mixture, and concentration-ladder data being used to refine mixture theory
Coating Design Software Overview

• Objective
  – optimize total solar reflectance given color, pigment constraints

• Algorithm
  – LBNL-adapted Kubelka-Munk theory

• Validation
  – compare computed, measured spectral reflectances of complex coatings

• Platform: “R” programming language
  – free
  – available for PC, Mac, Unix
  – http://www.r-project.org
Next Steps

• Validate mixture theory
• Develop optimization algorithm
• Validate code in-house
• Share software prototype with partners for further testing
2.4.3 Develop Database of Cool-Colored Pigments

• Objective
  – Develop a database that can be readily used by the industry to obtain characteristic pigment information for the design of cool-colored coatings

• Deliverables
  – Electronic-format Pigment Database

• Schedule: 6/1/03 – 6/1/05

• Funds Expended 25%
Cool Colored Pigment Database: Updates

• Shared database with partners
  – Feedback requested

• Next step: add new data
  – Diluted black and white masstones
  – Tints
  – Pigmented glazes
2.5 Develop Prototype Cool-Colored Roofing Materials

- **Objective:** Work with manufacturers to design innovative methods for application of cool coatings on roofing materials

- **Subtasks:**
  - Review of roofing materials manufacturing methods
  - Design innovative engineering methods for application of cool coatings to roofing materials
  - Accelerated weathering testing
2.5.1 Review Roofing Materials Manufacturing Methods

• Objective: Compile information on roofing materials manufacturing methods

• Deliverables:
  – Methods of Fabrication and Coloring Report (prepared on July 1, 2003)

• Schedule: 6/1/02 – 6/1/03

• Funds Expended 98%
Focus: Application of Cool Colors to Roofing Products

- Metal roofing
- Clay roof tiles
- **Concrete roof tiles**
- Wood shakes
- Asphalt shingles (granules)
Manufacturing Concrete Roof Tiles

• On October 1, we visited the MonierLifetile concrete roofing tile plant in Lathrop, CA
Schematic of a Concrete Roof Tile Plant

- Pigments - cost savings - organic pigments
- Cementitious materials (tile body and coatings) - GGBS - CSA - Low energy cements - PFA - Alkali activated slag
- Aggregates & Fillers - grading - quarry waste - milled calcium carbonate - recycled aggregates
- Mortar preparation - mix design - mixing efficiency - batching efficiency - mortar flow
- Cement Silo
- Sand Silo
- Cement Silo BULK
- BULK Racker
- Batch Mixer
- Mould release oils - technical support
- Roller & Slipper Knife
- Surface coatings - inorganic - organic
- Coatings Dryer
- Post-Cure Coating
- Collation
- Packaging
- Curing Chambers
- Curing process - process specification - CFD modelling - airflow distribution
- Pigments Preparation
- Water - waste water
- Mortar preparation - mix design - mixing efficiency - batching efficiency - mortar flow
- Mould Return
- Tile Machine
Relative Proportions Of Raw Materials in a Tile

BASED ON WEIGHT

- Sand
- Cementitious materials
- Polymer coating
- Water
- Pigment
- Limestone filler

BASED ON COST

- Pigment
- Sand
- Polymer coating
- Cementitious materials
- Water
- Limestone filler
- Pallet Oil
Production of Cool Colored Concrete Roof Tiles

• Ways to improve solar reflectance
  – whiten tile by
    • using white cement in concrete mix;
    • using white cementitious surface coating; or
    • using white polymeric surface coating
  – use infrared-scattering colored pigments over light or dark tile
    • example: mixed-metal complex inorganics
  – use infrared-transmitting colored pigments over a light tile
    • example: phthalocyanines
Next Steps

• Visit a wood shake manufacturing plant
• Finalize the manufacturing report
2.5.2 Design Innovative Engineering Methods for Application of Cool Coatings To Roofing Materials

• Objective: Work with manufacturers to design innovative methods for application of cool coatings on roofing materials

• Deliverables:
  – Summary Coating Report
  – Prototype Performance Report

• Schedule: 6/1/02 – 12/1/04

• Funds Expended 40%
Recent Activities

• Collaborating with 12 companies
  – shingles/granules
  – tiles/tile coatings
  – metal/metal coatings
  – pigments

• Prototypes developed and characterized include (~)
  – 50 shingles
  – 30 tiles or tile coatings
  – 20 metal panels

• Iterative prototype development
  – pigment selection
  – choice of base coats
  – components to avoid
Example: Development of Cool Black Shingles

Prototype Cool Black Shingles

performance limit (R=0.25)
[25 micron smooth film over opaque white]

prototype 3 (R=0.18)
prototype 2 (R=0.16)
prototype 1 (R=0.12)
conventional black (R=0.04)
Progressively Improving Reflectance

Prototype Cool Black Shingles

Solar Reflectance

- Conventional: 0.04
- Prototype 1: 0.12
- Prototype 2: 0.16
- Prototype 3: 0.18
- Performance limit: 0.25
Example: Development of Cool Roof Tile Coatings

• Acrylic roof tile coatings suitable for new tiles, retrofits

• Color palette meets California’s Title-24 requirements for tile (reflectance \( \geq 0.40 \))
Measuring Reflectance of Non-Uniform Surfaces (e.g., Shingles)

- Monte-Carlo technique
  - measure reflectance in series of random locations until cumulative average stabilizes
Next Steps (Technical)

• Collaboration with industrial partners
  – pigments: identify/develop suitable undercoats with high NIR reflectance
  – review IR-reflective window technology for ideas
  – propose further recipes for high NIR-reflectance colors
  – investigate methods for factory measurement of shingle NIR reflectance
Manufacturing Constraints

- Cost of colorants
- Longevity of colorants
- Ability to apply multilayered coatings
- Pilot plant capacity for production of demonstration-home samples
Key Research Direction Issues: 2 Ways to Increase Solar Reflectance

1. Technical
   – Use infrared-reflecting undercoat
   – Use infrared-reflecting or infrared-transmitting topcoat

2. Marketing
   – Changing the consumer preference to accept lighter colors

old color  new color
Criteria for Selecting Roofing Shingles for Demonstration Houses

• Currently, we have budget for testing shingle products on two houses (one for standard color and one for cool color)
• The project currently requires testing of roofing materials with similar color
• We need to expand the demonstration sites to showcase all cool roofs in Northern and Southern CA
Next Steps (Demonstration)

• Develop selection criteria for testing shingle-roofed houses
• Continue working with partners to produce shingles for demonstration
• Continue working with partners to improve the reflectance of other roofing products
• Prepare samples for weathering farms in CA
2.6 Field-testing and Product Useful Life Testing

**Objective:** Demonstrate, measure and document the building energy savings, improved durability and sustainability of Cool Roof Color Materials

**Subtasks:**
- Building energy-use measurements at California demonstration sites
- Materials testing at weathering sites in California
- Steep-slope assembly testing at ORNL
- Product useful life testing
2.6.1 Building Energy-Use Measures at California Demonstration Sites

**Objective:** Setup residential demonstration sites; measure and document the energy savings of Cool Roof Color Materials

**Deliverables:**
- Site Selection: Cavalli Hills, Fair Oaks, CA
- Site Test Plan – Test Site Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 55%
Cavalli Hills Subdivision
Fair Oaks, CA

Sacramento Municipal Utility District (SMUD) and ORNL/LBNL will monitor homes

- Cool Roof Color Materials (CRCM)
- Insulated Concrete Form (ICF) walls
Cavalli Hills Success Story

Mike Evans Building Energy Efficient Homes For You

Evans Construction
EL Dorado Hills, CA 95762
Phone (916) 935 1854
Fax (916) 930 3419

COOL ROOF COLOR MATERIALS (CRCMs)
Most painted roofs today have a reflectance of about 10-20%, but special paints make using Cool Roof Color Materials can give you a much higher reflectance of almost 80%. A roof covered by this special paint absorbs less solar energy and can save nearly 20% of your air conditioning costs.

FERRI Corporation and the Shepherd Color Company developed the Cool Roof Color Materials to look dark in color even though they reflect more of the sun’s energy. How can these dark colors reflect so much more energy than a white roof? The sun’s radiation consists of ultraviolet, visible, and infrared energy. Our eyes can only see the visible portion. The visible light that is reflected from an object determines the color of that object. While roofs reflect most of the visible light (which means together to look white to our eyes), but over half of the sun’s energy is in the infrared region, which isn’t visible to our eyes. Because we can’t see this energy, we can reflect it away from the roof without changing the roof color.

Advantages of Cool Roof Color Materials
- Better heat resistance than standard colors
- Replaces metal signs and stay cooler
- Lower utility bill for cooling the house
- Architectural appeal

Insulated Concrete Form Walls
Oak Ridge National Laboratory and the Florida Solar Research Center independently proved that insulated concrete form wall construction reduces seasonal cooling energy. These walls save energy on hot sunny days, and they have a higher thermal resistance (R-value) than many other types of walls. Second, they tend to store energy, so that regular-day and night temperature swings can help cool the house in summer and warm the house in winter.

Special Testing
The Sacramento Municipal Utility District is working with Evans Construction because they want to collect thermal performance data for insulated concrete form walls in Sacramento. The California Energy Commission and two national laboratories, Oak Ridge National Lab and Lawrence Berkeley National Lab, are interested in knowing the performance of the Cool Roof Color Materials. So it makes good sense to work together in one project. Oak Ridge will make thermal scans of the house and walls. In these scans, cold surfaces show up black while the hottest surfaces are orange, red or white in color. The house will have ICF walls on the right show lower wall temperatures than the frame construction houses on the left, and therefore has lower heat losses.

Air leakage affects the thermal performance of a home, and can account for 30% or more of your home’s utility bill. Oak Ridge will conduct blower-door and duct testing to determine the natural infiltration rate of the house and duct system. Uncontrollable air leakage can result in high utility bills and moisture damage.

Cavalli Hills
By Encore Properties

12 NEW SINGLE FAMILY HOMES
Starting In The Low $400,000’s

Framentos’ First Subdivision Featuring:
Insulated Concrete Form Construction

3 FLOOR PLANS, 1,404 TO 1,484 SQ FT
SMUD CUSTOMER ADVANCED TECHNOLOGIES

By Steve Burke (916) 812-7522
Sacramento Real Estate

Cavalli Hills
(12 homes sold)
A Style Home Finished with Hanson Roof Tile and Stucco
C Style Home Finished with Painted Metal Shingle and Stucco
Second A Style Home Finished with Hanson Roof CRCM Tile and Stucco
Thermal buoyancy and wind forces affect attic ventilation

- Attic air temperature calculated for several different ventilation rates.

![Graph showing attic air temperature over July 1 - 7 (hours into week) for different ventilation rates: 0.0 ACH, 0.5 ACH, 2.4 ACH, and variable vent rate. Outdoor air temperature is also shown.](image)
2.6.1 Next Steps

- **American Roof Tile Coatings**
  Topcoat applied to Hanson’s Hacienda concrete tile

- **Custom-Bilt Metals & Classic Products**
  *Country Manor Shake*: Musket Brown 31% reflective

- **ORNL and SMUD commission DAS**

- **Establish Second Demonstration Site**
  Composition shingles
2.6.2 Materials Testing at Weathering Sites in California

**Objective:** Document the change in reflectance and emittance for roof products having Cool Roof Color Materials

**Deliverables:**
- Weathering Studies Report
- Schedule: 10/1/02 – 10/1/05
- Funds Expended 40 %
Samples exposed for 6 months

CA Topographic Map

Field Exposure Sites

<table>
<thead>
<tr>
<th>Sites</th>
<th>Company</th>
<th>City</th>
<th>County</th>
<th>Climate Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Custom-Bilt</td>
<td>Sacramento</td>
<td>Sacramento</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Steelscape</td>
<td>Richmond</td>
<td>Contra Costa</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>BASF</td>
<td>Colton</td>
<td>San Bernadino</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Maruhachi Ceramics of America</td>
<td>Corona</td>
<td>Riverside</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>ELK Corporation</td>
<td>Shafter</td>
<td>Kern</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>Department of Water Resources</td>
<td>McArthur</td>
<td>Shasta</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>Department of Water Resources</td>
<td>Meloland</td>
<td>Imperial</td>
<td>15</td>
</tr>
</tbody>
</table>

Shuttle Radar Topography Mission (SRTM)
Space Shuttle Endeavor
National Imagery and Mapping Agency (NIMA)
Samples exposed in substantially different CA climates

Shafter

Corona

Meloland
Reflectance Measures for Painted Metals

<table>
<thead>
<tr>
<th>D&amp;S $\rho$ minus Spectrometer $\rho$</th>
<th>ORNL</th>
<th>LBNL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>-0.009</td>
<td>-0.004</td>
</tr>
<tr>
<td>Max</td>
<td>0.078</td>
<td>0.051</td>
</tr>
<tr>
<td>Mean</td>
<td>0.022</td>
<td>0.019</td>
</tr>
</tbody>
</table>

- **ORNL D&S Reflectometer**
- **LBNL D&S Reflectometer**
- **LBNL Spectrometer**

Reflectance ($\rho$): Regal White, Rawhide, Brick Red, Hartford Green
Reflectance Measures for Clay Tile

<table>
<thead>
<tr>
<th></th>
<th>D&amp;S $\rho$ minus Spectrometer $\rho$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ORNL</td>
</tr>
<tr>
<td>Min</td>
<td>0.024</td>
</tr>
<tr>
<td>Max</td>
<td>0.070</td>
</tr>
<tr>
<td>Mean</td>
<td>0.045</td>
</tr>
</tbody>
</table>
Reflectance and Emittance of painted metals at exposure sites

### Reflectance ($\rho$)

<table>
<thead>
<tr>
<th></th>
<th>Regal White</th>
<th>Rawhide</th>
<th>Brick red</th>
<th>Charcoal Gray</th>
<th>Hartford Green</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>0.69</td>
<td>0.44</td>
<td>0.20</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>CRCM</td>
<td>0.74</td>
<td>0.57</td>
<td>0.37</td>
<td>0.31</td>
<td>0.27</td>
</tr>
<tr>
<td>Difference</td>
<td>0.05</td>
<td>0.13</td>
<td>0.17</td>
<td>0.19</td>
<td>0.18</td>
</tr>
</tbody>
</table>

### Emittance ($\varepsilon$)

<table>
<thead>
<tr>
<th></th>
<th>Regal White</th>
<th>Rawhide</th>
<th>Brick red</th>
<th>Charcoal Gray</th>
<th>Hartford Green</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>0.81</td>
<td>0.87</td>
<td>0.83</td>
<td>0.86</td>
<td>0.83</td>
</tr>
<tr>
<td>CRCM</td>
<td>0.82</td>
<td>0.83</td>
<td>0.82</td>
<td>0.83</td>
<td>0.81</td>
</tr>
<tr>
<td>Difference</td>
<td>+0.01</td>
<td>-0.04</td>
<td>+0.01</td>
<td>-0.03</td>
<td>-0.02</td>
</tr>
</tbody>
</table>
2.6.2 Next Steps

- Recall samples for measurements
- Deploy new concrete samples
- Develop CIMIS weather database
- Continue reflectance checks with spectrometer
2.6.3 Steep-slope Assembly Testing at ORNL

**Objective:** Field test Cool Roof Color Materials on the Envelope Systems Research Apparatus (ESRA) to document the effect of reflectance and emittance weathering on thermal performance

**Deliverables:**
- Attic Model Validation
- Presentation at the Pacific Coast Builders Conference
- Steep Slope Assembly Test Report

- Schedule: 10/1/02 – 10/1/05
- Funds Expended **35 %**
Roof Tile Institute installed five different tile assemblies on ESRA

<table>
<thead>
<tr>
<th>Lane</th>
<th>Type of Tile</th>
<th>Manufacturer</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clay &quot;S&quot;</td>
<td>MCA</td>
<td>Direct Deck</td>
</tr>
<tr>
<td>2</td>
<td>Concrete Medium</td>
<td>Hanson</td>
<td>Direct Deck</td>
</tr>
<tr>
<td>3</td>
<td>Concrete Medium</td>
<td>MonierLife Tile</td>
<td>Direct Deck with foam</td>
</tr>
<tr>
<td>4</td>
<td>Concrete Flat</td>
<td>MonierLife Tile</td>
<td>Counter Batten</td>
</tr>
<tr>
<td>5</td>
<td>Concrete &quot;S&quot;</td>
<td>Eagle</td>
<td>Batten</td>
</tr>
<tr>
<td>6</td>
<td>Asphalt Shingle</td>
<td></td>
<td>Direct Deck</td>
</tr>
</tbody>
</table>
The ESRA has a New Look
Flat-plate solar collector excellent starting point for formulating tile roof heat transfer correlations

\[ Ra_{L,\text{Critical}} \leq 1708 / \cos(\theta) \]
Lafarge Roofing Technical Center (Sussex, UK) wants to collaborate

- radiant barriers in northern U.S. climates
- condensation prediction in batten roofs
- heat flux prediction in roofs
2.6.3 Next Steps

- Programming of ESRA DAS
  Instrument attic cavities
- Flow Visualization Studies
  Lafarge Roofing Technical Center
- Validation of AtticSim code
  Venting between deck and roof tile
Collaboration and Tech Transfer


September 2004 Meeting

- September 9, 2004
- At ORNL, Oak Ridge, TN
Cool Colors Project Website

• Project information (including copies of this presentation) available online at http://CoolColors.LBL.gov