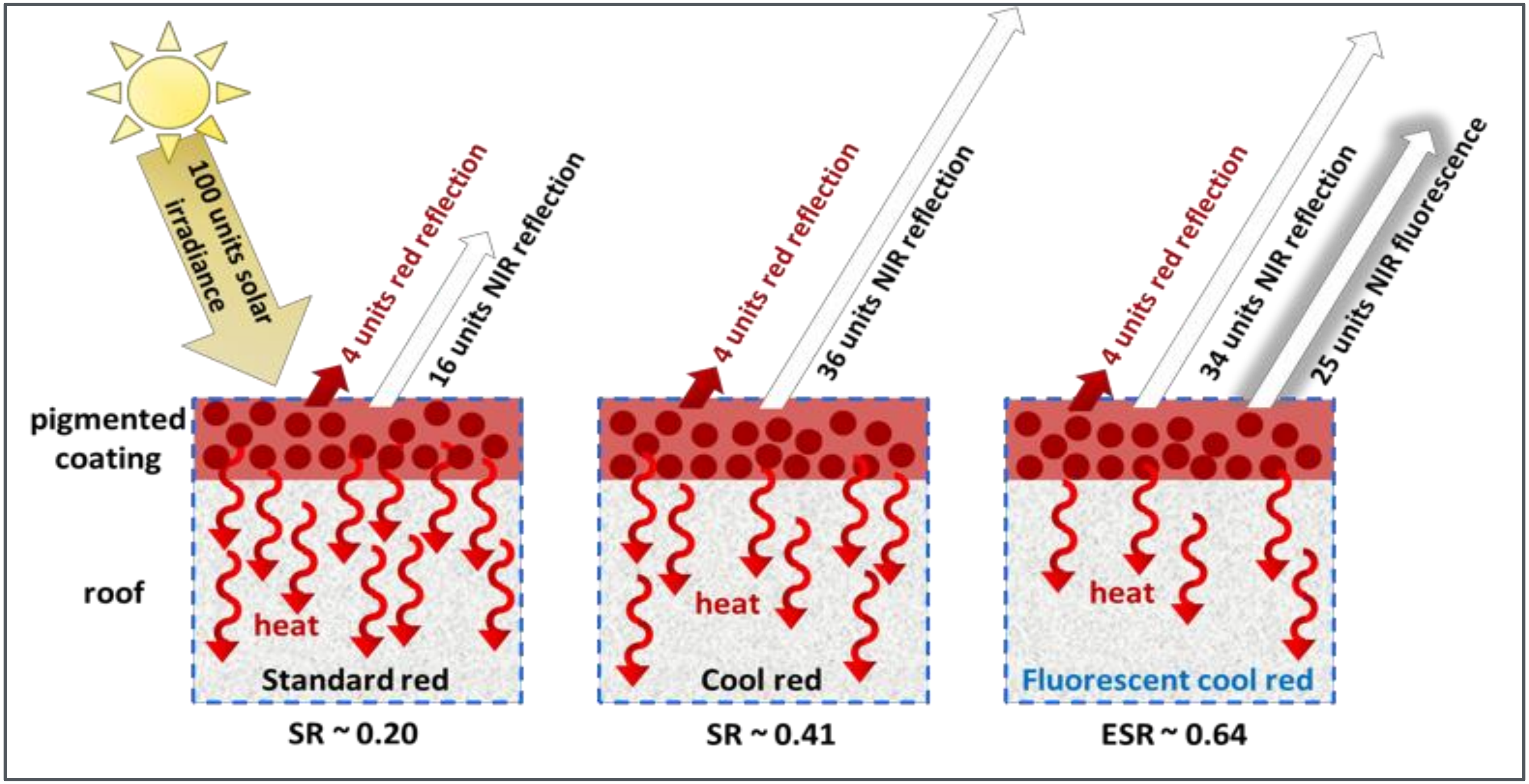
Fluorescent Pigments for High-Performance Cool Roofing

2015 Building Technologies Office Peer Review



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Project Summary

Timeline:

Start date: October 1, 2013

Planned end date: September 30, 2015

Key Milestones

1. Additional Pigments Identified, End Q2 and Q6
2. 500g of 2 New Pigments, End Q3 and Q7
3. ESR Measured on New Cool Roof Coating, End Q4 and Q8
4. Potential Manufacturing Partner, Q3 and ongoing
5. Update BTO Prioritization Tool, Q8

Budget:

Total DOE $ to date: $474,132

Total future DOE $: $0

Target Market/Audience:

Residential Roofing Sector

Key Partners:

PPG Industries, Inc.
Lawrence Berkley National Lab

Project Goal:

This project will develop novel dark-colored, cool pigments that combine near-infrared (NIR) fluorescence with NIR reflectance. These novel pigments will obtain unprecedented effective solar reflectance (ESR) values for dark-colored coatings to be used in the Building Envelope segment.

Purpose and Objectives

Problem Statement: State of the art solar reflectance and therefore building performance is limited by the nature of the NIR pigments used in cool roof coatings.

Target Market and Audience: The target market is the steep metal roof market. Residential market roofs in Climate Zones 4 & 5 could save 124 TBTU by deploying traditional cool roof technology*. By scaling this savings with the fluorescent pigment improvement, the savings increases to 165 TBTU.

Impact of Project: PPG is already supplying Cool Roof products into the market. By developing novel pigments and incorporating them into roof coatings, we have the ability to increase the energy savings from Cool Roof applications. Since color is important, this project investigates how we can provide a range of different pigment options. This project is a proof of concept, that can lead to subsequent government or private investment to bring this technology to the market. We are measuring progress by the ESR achieved in the lab-scale prototype coatings. The ESR goal for dark coatings is 0.5 to 0.7.

* R. Levinson, The case for cool roofs, LBNL (May 7, 2012)

Approach

Approach: This two year project (one year with a 12 month no-cost extension) was divided into two phases: Pigment Development/Characterization, and Coating Formulation and Testing. LBNL identified and characterized candidate pigments; PPG evaluated the fluorescence properties. A pigment manufacturer scaled up pigments of interest and PPG formulated 'cool' coatings using these pigments. Effective solar reflectance (ESR) measurements on final coated substrates were conducted at LBNL.

Key Issues: Some pigments do not disperse easily in coatings. Color shift of the commercial color palette would need to be considered by the SBU. Demonstrated long-term durability is required for commercialization.

Distinctive Characteristics: LBNL scaled up the ruby pigment via combustion synthesis and a pigment manufacturer scaled up ruby and additional pigments.

Progress and Accomplishments

Lessons Learned: Even though a pigment may demonstrate intense NIR fluorescence, a significant amount of NIR fluorescent pigment needs to be added to existing 'cool' coating formulations to achieve detectable fluorescence. Coil and extrusion coatings are applied at dry film thicknesses of *ca.* 0.8 mils (20 µm), which limits the amount of pigment that can be added. The amount of pigment in the film needs to be balanced with other components in the formulation to maintain acceptable color and coating properties.

Accomplishments: Several pigments that exhibit fluorescence in the NIR were identified and incorporated into coatings. A pigment manufacturer was engaged and they were able to produce large quantities of pigments for experimentation. Samples were produced that show improved ESR due to fluorescence.

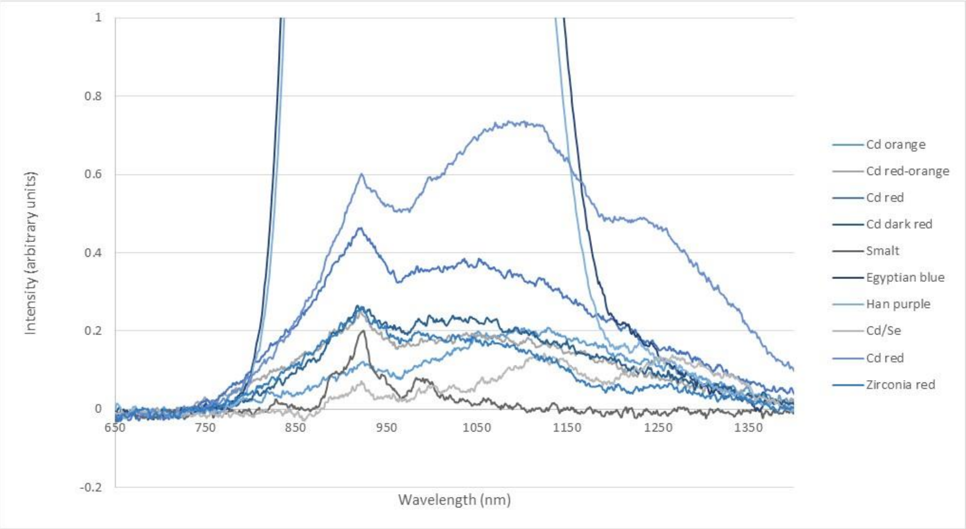
Market Impact: Coatings based on these pigments can satisfy consumer demand for dark colors on building surfaces, and contribute to achieving the DOE's goal of building envelope energy savings of 20% compared to 2010 levels. Upcoming LEED V4 requires 30% SR, up from 25% SR. Some coatings that were "cool" will not meet the new standard, although other performance standards vary.

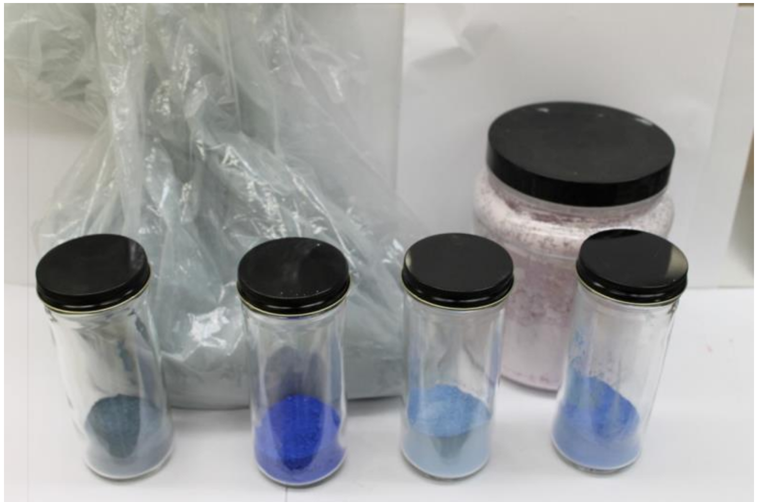
Awards/Recognition: Nothing to report at this time.

Pigment Development and Characterization

- Over 30 pigments were evaluated for NIR fluorescence
- At least 10 pigments demonstrated some NIR fluorescence

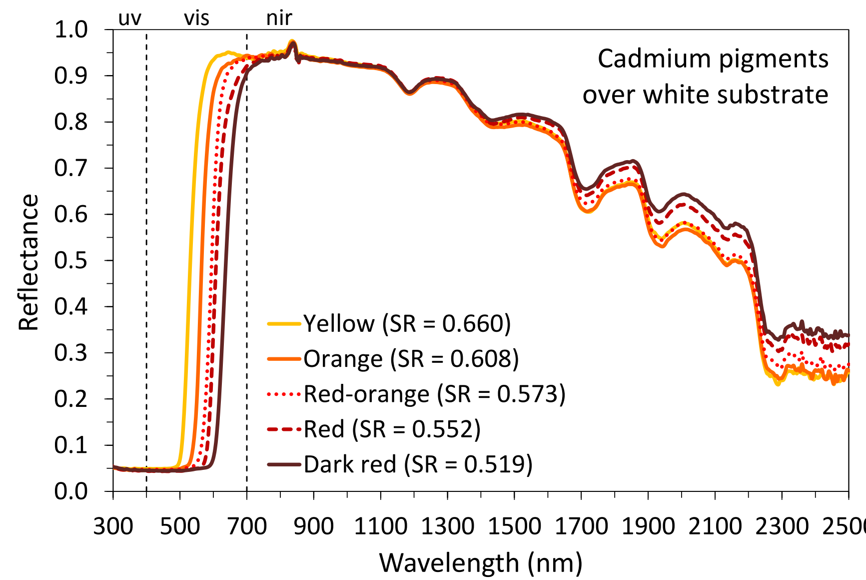
- A commercial pigment manufacturer was engaged to produce larger volumes of NIR fluorescent pigments (200 g to 2,000 g): Egyptian blue, Han blue, Blue 1, Blue 4 and ruby

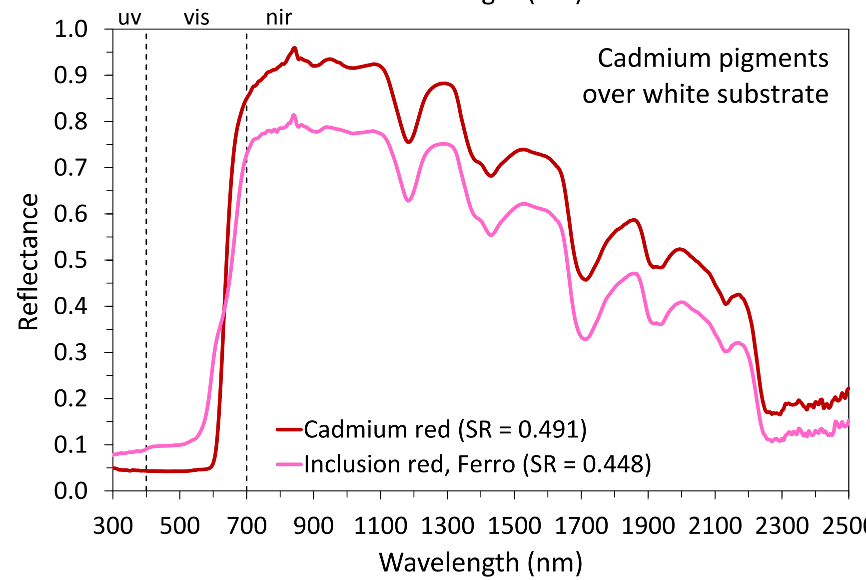




Cadmium pigments – untapped potential

- Reflectance spectra are nearly ideal for cool pigments, even without fluorescence
- Great potential; see fluorescent nanoparticle research:
  - 30% quantum efficiency in CdSe
  - ~100% quantum efficiency in CdTe
- If necessary, toxicity associated with Cd mitigated with coatings on the particles (e.g., inclusion pigments of Ferro)
- For current pigments and reagent powders, fluorescence is weak due to defects and lack of surface passivation
- A selective black based on Cd(S,Se) could have ESR well above 0.5





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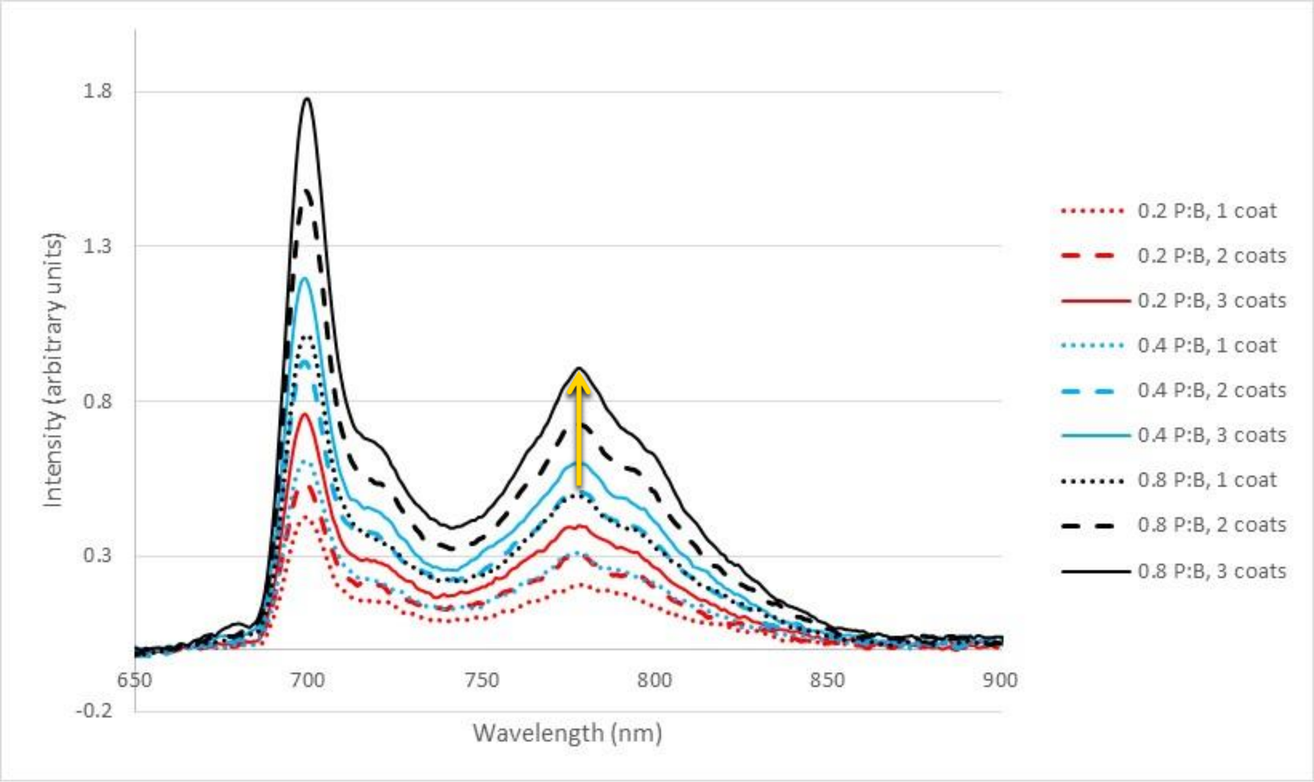
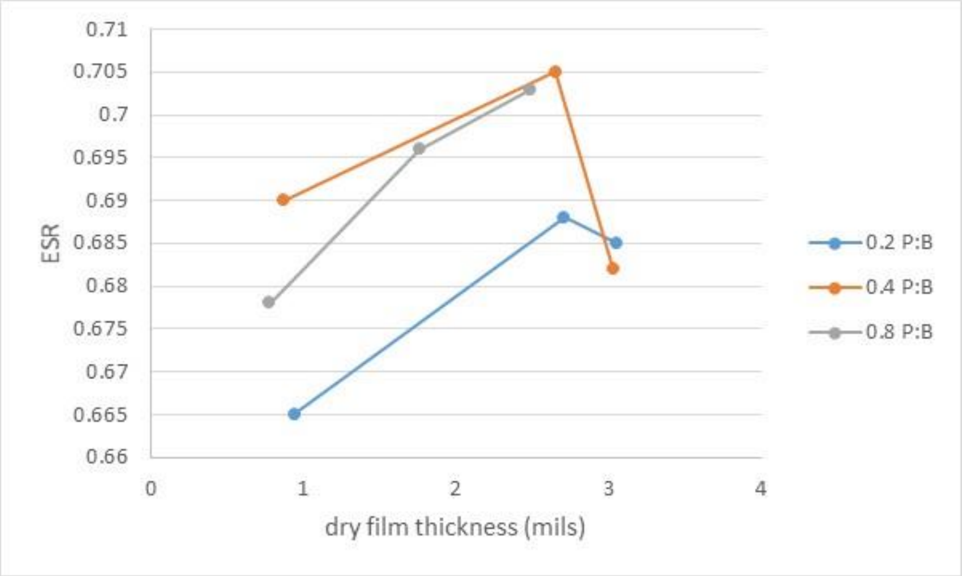
Formulation study of ruby in PPG coatings

- A study was conducted to observe the impact of NIR fluorescent pigment loading and film thickness on NIR fluorescence of a coating
  - 0.2, 0.4 and 0.8 P:B (pigment to binder ratio based on mass) coatings were prepared and applied at three film thicknesses (1 coat, 2 coats, 3 coats)



ESR measurements of ruby formulation study

Coating P:B	Film thickness mils (µm)	ESR
0.2	0.94 (23.8)	0.665
0.2	2.71 (68.8)	0.688
0.2	3.05 (77.5)	0.685
0.4	0.87 (22.1)	0.690
0.4	2.65 (67.3)	0.705
0.4	3.03 (77.0)	0.682
0.8	0.78 (19.8)	0.678
0.8	1.76 (44.7)	0.696
0.8	2.49 (63.2)	0.703



- ESR values increase as the film thickness values increase
- ESR values increase as P:B (pigment loading) increases
- Noise of ESR test contributes to data scatter (0.01)

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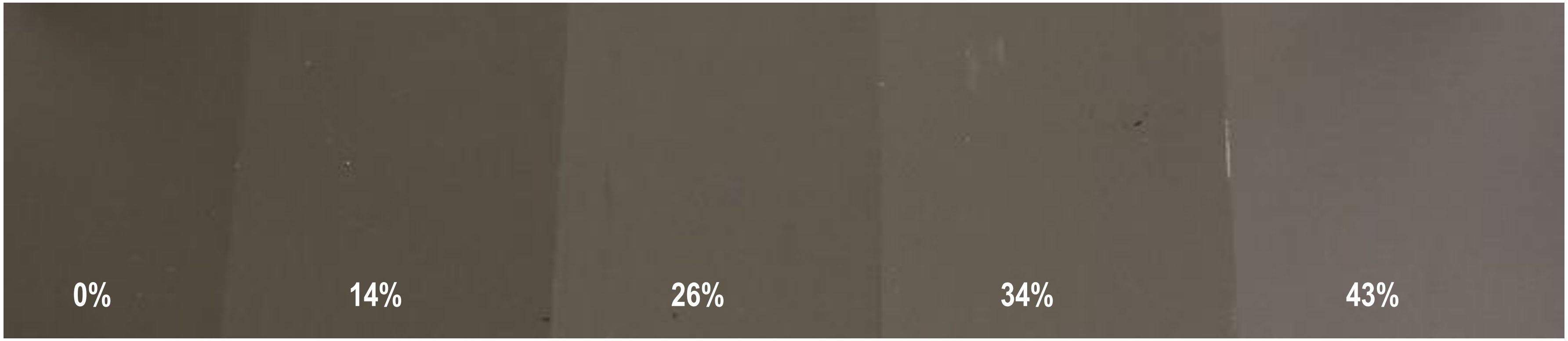
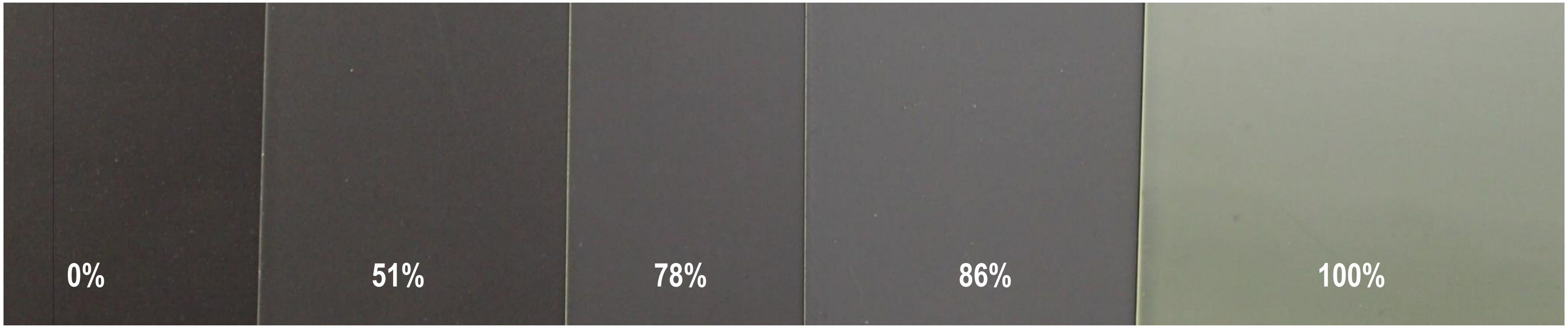
NIR fluorescent pigments as co-pigments in commercial Duranar® 'cool' coatings

Duranar® brown topcoat with different levels of ruby



Wt % ruby in film

Duranar® black topcoat with different levels of Han blue



Wt % Han blue in film

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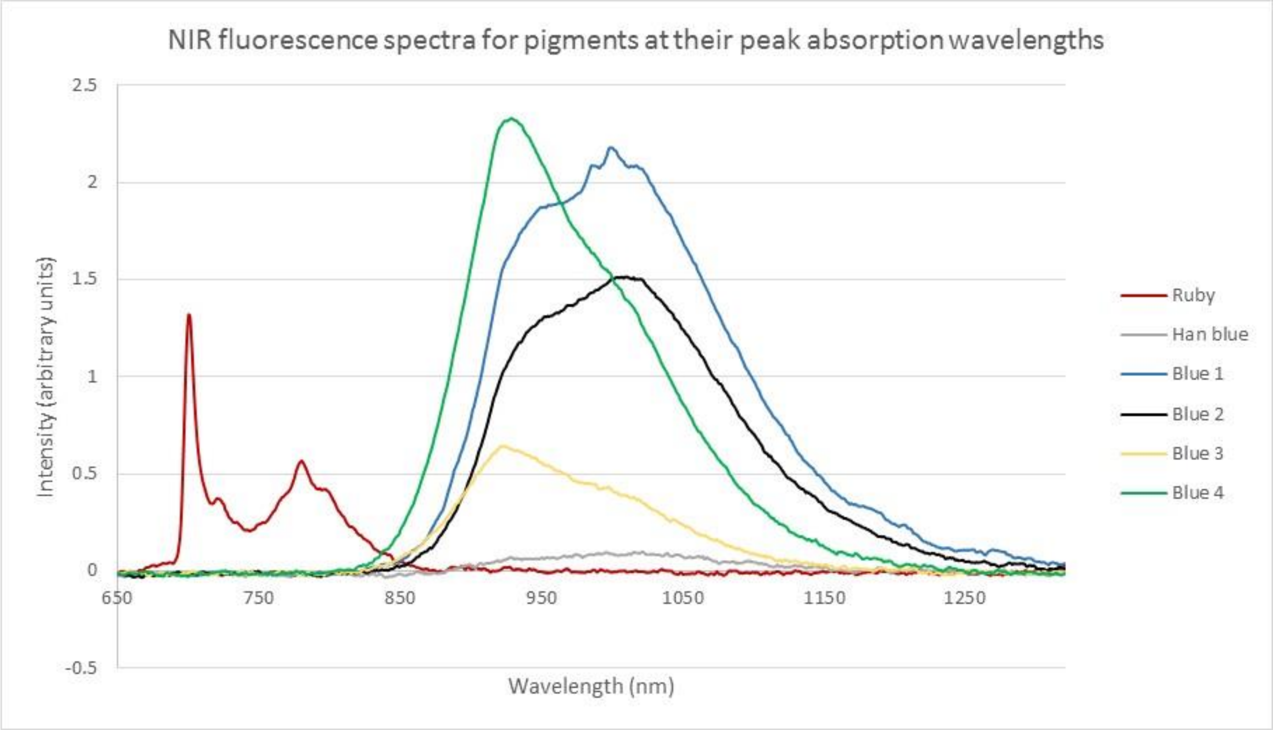
New blue pigments offer boost in fluorescence and ESR values



Blue 1 over white primer

Duranar ® Vari-Cool™ Jamaican Reef Blue

Blue 4 over white primer

Fluorescence contributes *ca*. 0.04 – 0.05 units to the ESR values

Project Integration and Collaboration

Project Integration: LBNL has identified numerous candidate pigments that were evaluated for NIR IR fluorescence by LBNL and PPG. Candidate pigments were scaled up by a commercial pigment manufacturer to allow for further experimentation with pigments of the appropriate particle size.

Partners, Subcontractors, and Collaborators: A commercial pigment manufacturer was engaged to prepare pigment samples.

Communications: Quarterly project reviews with DOE in addition to internal project team meetings.

- R. Levinson gave a plenary talk at the Heat Island Countermeasures conference in Venice (October 2014) on LBNL Heat Island research, which included a description of the PPG/LBNL NIR fluorescent pigment project
- A provisional patent application was filed by LBNL in 2014 on cool fluorescent pigments. A full patent application was filed in March 2015.
- Haas School of Business at UC Berkeley held a business case competition as part of their 8th Annual BERC (Berkeley Energy and Resources Collaborative) Energy Summit meeting in October 2014. LBNL provided assistance to two UCB graduate students (S. Leblebici and A. van Schilfgaarde) who presented on the subject of cool fluorescent pigments for electrical vehicles. They won the competition.

Next Steps and Future Plans

Next Steps: Complete Phase 2 activities

- Determine candidate colors for fluorescent pigments
- Evaluate durability of coatings (Florida exposure and accelerated weathering testing)
- Conduct ESR testing on commercial coatings containing different levels of NIR fluorescent pigments
- Determine if the solar reflectance of PPG coatings that have SR values below 0.3 can be improved to having ESR values above 0.3 (LEED V4)

Future Plans: Enhance BTO's Cool Roof mission by addressing limitations of pigments (efficiency, stability, toxicity…); address other façade surfaces (especially cool walls) and perhaps automotive applications

REFERENCE SLIDES

Project Budget

Project Budget: $530,165 (PPG + LBNL, including cost share)
Variances: level of effort is lower than planned, leading to a slightly reduced level of spending.
Cost to Date: $188,371

Budget History					
FY2014 (past)		FY2015 (current)		FY2016 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$58,105	$14,526	$166,028	$41,507	$0	$0

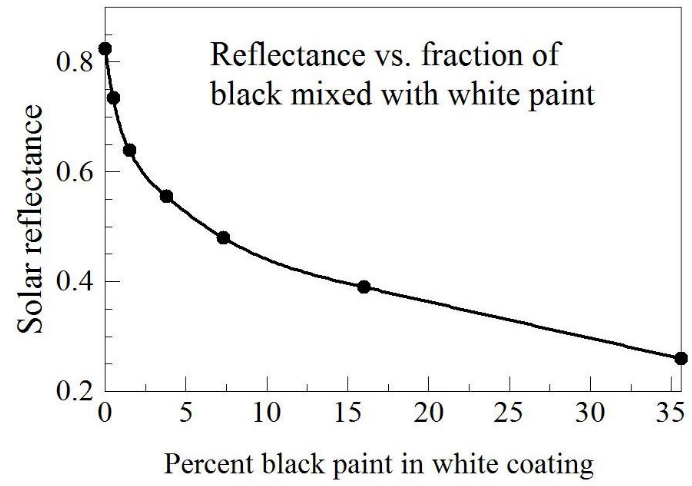
Project Plan and Schedule

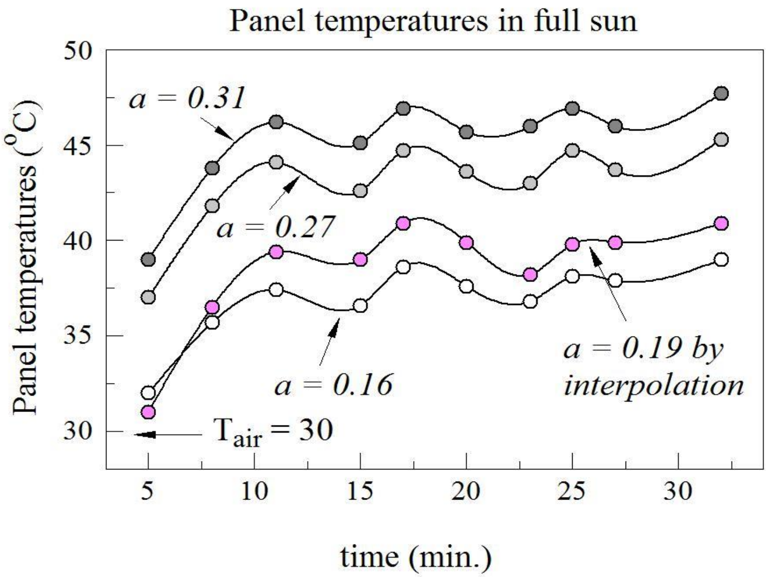
Project Schedule		
Project Start: Insert Start Date		Completed Work
Projected End: Insert End Date		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned) use for missed
		Milestone/Deliverable (Actual) use when met on time

	FY2013				FY2014				FY2015			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Two hundred grams of dark red pigment												
A consistent and reproducible test methodology												
A dark red coating will be formulated												
Provide initial estimates												
10 additional pigments synthesized												
Produce other pigments												
Five hundred gram batches												
Potential manufacturing partner identified												
Current/Future Work												
ESR of pigments measured												
Update BTO Prioritization Tool												
Five hundred gram batches II												
ESR of pigments measured II												

Effective Solar Reflectance (ESR) determination

- Calibrated non-fluorescent samples prepared: mixture of white and black paint on metal substrates
- Spectrometer determines SR
- Temperature measurements taken outside in full sun
- Solar absorptance a of unknown fluorescent sample determined by interpolation
- ESR = 1 - a



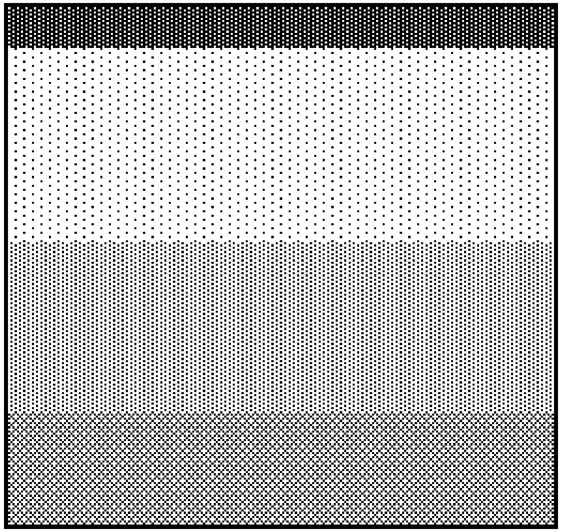


From 2014 Review

Incorporating Pigments into Paint

Paint Consists of

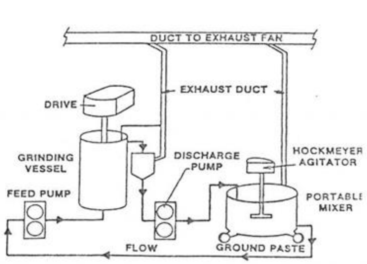
- Binder
  - Resin
  - Polymer
  - Vehicle
- Pigment
- Additives
- Solvent



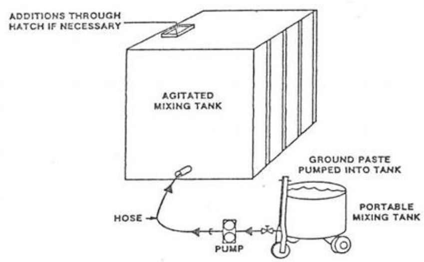
From 2014 Review

Incorporating Pigments into Paint

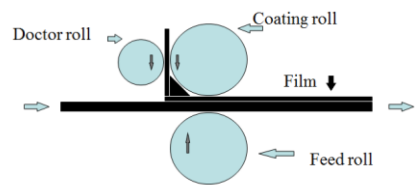
Pigment dispersion with high speed dispersing blade or grind media



→ Letdown with additional resins/additives/ solvents



→ Apply coating to substrate (spray, roll, dip, etc.)



→ Cure coating (ambient or heat)

→ Test coating

From 2014 Review