Environment and Natural Resources Trust Fund
2018 Request for Proposals (RFP)

Project Title: **ENRTF ID: 170-E**

Color-Change Solar Coating for Residential Energy Savings

Category: E. Air Quality, Climate Change, and Renewable Energy

Total Project Budget: $ 151,306

Proposed Project Time Period for the Funding Requested: 2 years, July 2018 to June 2020

Summary:

In this study, lab and field tests assess residential building heating and cooling cost savings by using color-changing exterior coatings, possibly yielding millions of dollars in savings for Minnesota consumers.

Name: John Sinko

Sponsoring Organization: St. Cloud State University

Address: 720 Fourth Avenue South

St. Cloud MN 56301

Telephone Number: (320) 308-4932

Email ResearchNow@stcloudstate.edu

Web Address www.stcloudstate.edu

Location

Region: Central

County Name: Stearns

City / Township: St. Cloud

Alternate Text for Visual:

Structure diagram of color-change coating and illustration of application on buildings

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%

PROJECT TITLE: Color-Change Solar Coating for Residential Energy Savings

I. PROJECT STATEMENT

We will develop, test, and analyze a multi-layer, color-changing coating that can switch between a dark absorbing state in the winter and a bright reflecting state in the summer to reduce residential energy costs in Minnesota. In our concept, a top transparent surface layer passes light but traps heat, a middle dye layer switches to dark or light states, and a bottom aluminum layer supports the coating and distributes heat. The idea is an inexpensive analogue of traditional building siding with the added bonus of energy savings; it could be added to new constructions or replace traditional siding. By switching the coating between states that trap or reflect sunlight, a building's interior temperature can be regulated. In cold weather, the coating darkens to trap sunlight, warm the building interior, and offset heating needs. In hot weather, the coating whitens to reflect sunlight away, keep the building cool, and cut air conditioning needs. The work will build on an $8,000 internal research grant which built a laboratory thermal test stand and completed preliminary experiments with heating of a color-changing dye layer.

The problems we are addressing are energy costs and unsustainable energy use. Minnesota currently imports billions of dollars of energy resources from other states, including natural gas and coal – the largest sources of energy for heating and cooling. Approximately 49% of a residential consumer's energy use is for home heating and cooling. Residential consumers make up 22.5% of total energy consumption in Minnesota. Home heating and cooling accounts for about $2.5 billion annually. The extreme temperature swings from summer to winter pose unique challenges in Minnesota; in particular, heating in the winter is not optional. However, moderate reductions in energy use for heating in winter and air conditioning in summer can produce millions of dollars in cost savings for Minnesota consumers.

Specific goals of this project are:

- To develop a multi-layer, color-changing coating to regulate heat and cut residential energy use
- To determine and analyze coating aging against ultraviolet radiation and temperature cycles
- To build and test five single room, 64 ft^2 'houses' coated with traditional paint versus color-change coatings to determine if significant cost savings can be achieved.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Create and Analyze Color-Change Coatings in the Laboratory **Budget: $ 79,508**

Five candidate commercial color-change materials will be tested which switch from black (cold) to white (hot) at different temperatures. We will analyze chemical structures, color change temperatures, percent reflectance hot and cold, the particle sizes, and heating rates. Starting from existing non-toxic commercial chemical stems, non-toxic color-changing derivatives will be synthesized. The color-change chemicals will be assembled into multi-layer coatings about as thick as a sheet of paper. A wire resistance thermometer ("wire thermistor") will be embedded into the coating to measure its internal temperature. About 45% of sunlight is infrared ('heat rays'), so chemical changes will be made to color-switch heat as well as light, doubling the coating efficiency. To determine if heat is switched, near-infrared spectroscopy is needed. This technique measures the reflected fraction of heat across the spectrum. We will control sample temperature with our laboratory's thermal test stand. A mathematical model will be derived from experimental results to predict how the heating of the coating depends on the intensity of sunlight.

Outcomes	Completion Date
Measure temperature rise for illuminated color-switching coating in lab tests	12/2018
Conduct visible and near-infrared spectroscopy tests for hot and cold coating	6/2019
Develop model to predict the coating temperature in sunlight and shade	12/2019

Activity 2: Practical Tests of Color-Change Coating for Outdoor Environments **Budget: $ 71,798**
Five test 'houses' (64 ft^2 floor space each) built on St. Cloud State University (SCSU) land will practically assess energy savings and coating durability. Building exteriors will be: (1) traditional dark paint, (2) traditional light paint, (3) color-change coating on exterior walls, (4) color-change coating on roof, and (5) color-change coating on both walls and roof. Interior and surface temperatures of the buildings will be recorded throughout one year by digital thermometers, light sensors, and a thermal camera. Separately, samples of the color-change coating will be sent to a professional environmental testing service to simulate one year of thermal cycling and ultraviolet exposure. Follow-up tests and analysis will be conducted at SCSU.

Outcomes	Completion Date
Build prototype 'houses', apply coatings, install sensors	3/2019
Record and analyze 'house' data for temperature, sunlight intensity, wind, etc.	6/2019
Simulate environmental exposure of coating samples (UV light & thermal cycling)	6/2020

III. PROJECT STRATEGY

A. Project Team/Partners

Our multidisciplinary project team includes St. Cloud State University researchers from the Departments of: Physics & Astronomy, Chemistry & Biochemistry, and Atmospheric & Hydrologic Sciences.

Project Partners Receiving Funds:

- Dr. John Sinko, Assistant Professor, Dept. of Physics & Astronomy

As the group's optical and thermal physics expert, Dr. Sinko will assess solar intensity and heating data, near infrared spectroscopy, and ultraviolet light exposure effects in the lab, and will develop thermal models to predict how the coating temperature behavior depends on sunlight intensity.

- Dr. Kannan Sivaprakasam, Associate Professor, Dept. of Chemistry & Biochemistry

As the chemical and materials expert of the group, Dr. Sivaprakasam will analyze the thermal chemistry of the color-change dyes, characterize particle sizes, synthesize or modify chemicals for desired properties, and explore chemical changes in the coating due to ultraviolet exposure.

- Dr. Chieh 'Jeff' Cheng: Associate Professor, Dept. of Atmospheric & Hydrologic Sciences

An expert in fluid mechanics and environmental science with a degree in civil engineering, Dr. Cheng will guide construction of test 'houses', assist with analysis of convective cooling by wind, and seek industrial partners. Dr. Cheng is an active registered Professional Engineer in the state of Colorado.

B. Project Impact and Long-Term Strategy

Project impacts include (1) chemical synthesis of new and improved color-changing dyes with better color-switching in the infrared spectrum and resistance to UV light, (2) deeper understanding of how multi-layer color-change coatings respond to sunlight exposure, (3) construction of five test 'houses' embedded with thermal sensors for use in future energy studies, (4) development of relationships with industrial partners to develop and implement color-change coatings for energy savings, and (5) if applied statewide, millions of dollars of savings for consumers in heating and cooling costs.

C. Timeline Requirements

Our project period will last two years, from July 2018 to June 2020. From July 2018-March 2019, lab tests will study the coating material. Test 'houses' will collect data from March 2019-March 2020. Chemical synthesis will proceed throughout the period of study. Environmental simulation takes two-three months and will be conducted in early 2020. Another proposal is in development for a Renewable Energy Materials REU grant, to be submitted in August 2017, which could support students in this work in summers 2018-2020. If justified, the next phase of study would scale up application of color-change coatings to buildings throughout Minnesota for a pilot study on energy savings.

2018 Detailed Project Budget

Project Title: Color-Change Solar Coating for Residential Energy Savings

IV. TOTAL ENRTF REQUEST BUDGET: 2 years

BUDGET ITEM	AMOUNT	
Personnel:		$104,316
John Sinko, Project Manager (63% salary, 37% benefits); 12.5% FTE for each of 2 years	$ 25,198	
Jeff Cheng, fluids scientist (63% salary, 37% benefits); 12.5% FTE for each of 2 years	$ 30,455	
Kannan Sivaprakasam, materials chemist (63% salary, 37% benefits); 12.5% FTE for each of 2 years	$ 27,054	
2 Student Research Assistants- data monitoring and analysis (92% salary, 8% benefits); 12.5% FTE for each of 2 years	$ 21,609	
Professional/Technical/Service Contracts:		$10,000
Environmental testing service TBD: ultraviolet and thermal cycle tests of coating samples to simulate 1 year of environmental exposure	$ 10,000	
Equipment/Tools/Supplies:		$36,990
Lab supplies: color-changing dyes, chemicals, paints, solvents, glassware, gloves	$ 2,000	
2 IR thermometers at ($270 each)	$ 540	
1 Infrared camera for quantitative visual analysis of structure heating	$ 800	
10 Thin wire thermisters ($65 each)	$ 650	
Near-infrared spectrometer for analysis of light and heat reflection across the spectrum	$ 30,000	
Building supplies for 5 testbed 'houses': lumber and plywood ($1500), 5 doors ($500), cement blocks for 5 bases ($100), hardware for assembly ($50), 5 window AC units ($750), 5 space heaters ($100)	$ 3,000	
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =		$151,306

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	$ -	
Other State $ To Be Applied To Project During Project Period:	$ -	
In-kind Services To Be Applied To Project During Project Period: 12% of total direct costs for Facilities and Administrative costs not applied to the project	$ 18,157	Secured
Past and Current ENRTF Appropriation:	$ -	
Funding History: $8,000 - 2014 St. Cloud State University: New Researcher Award	$ 8,000	

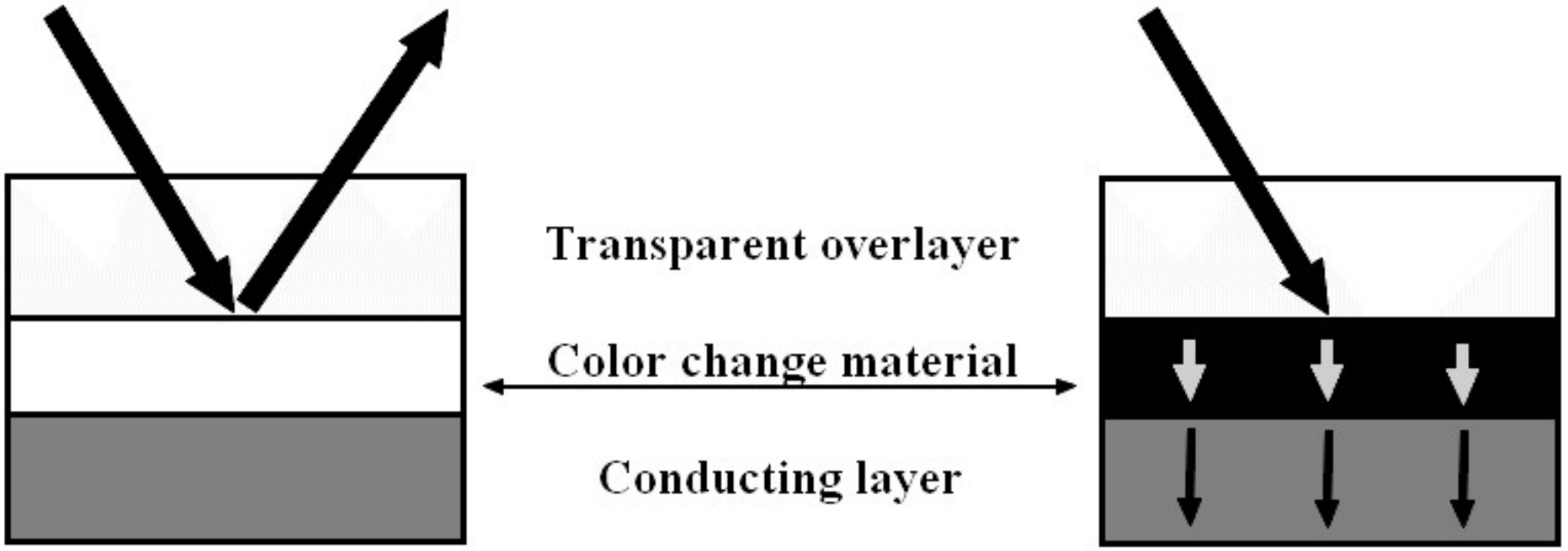
Exterior color-change coatings for energy savings

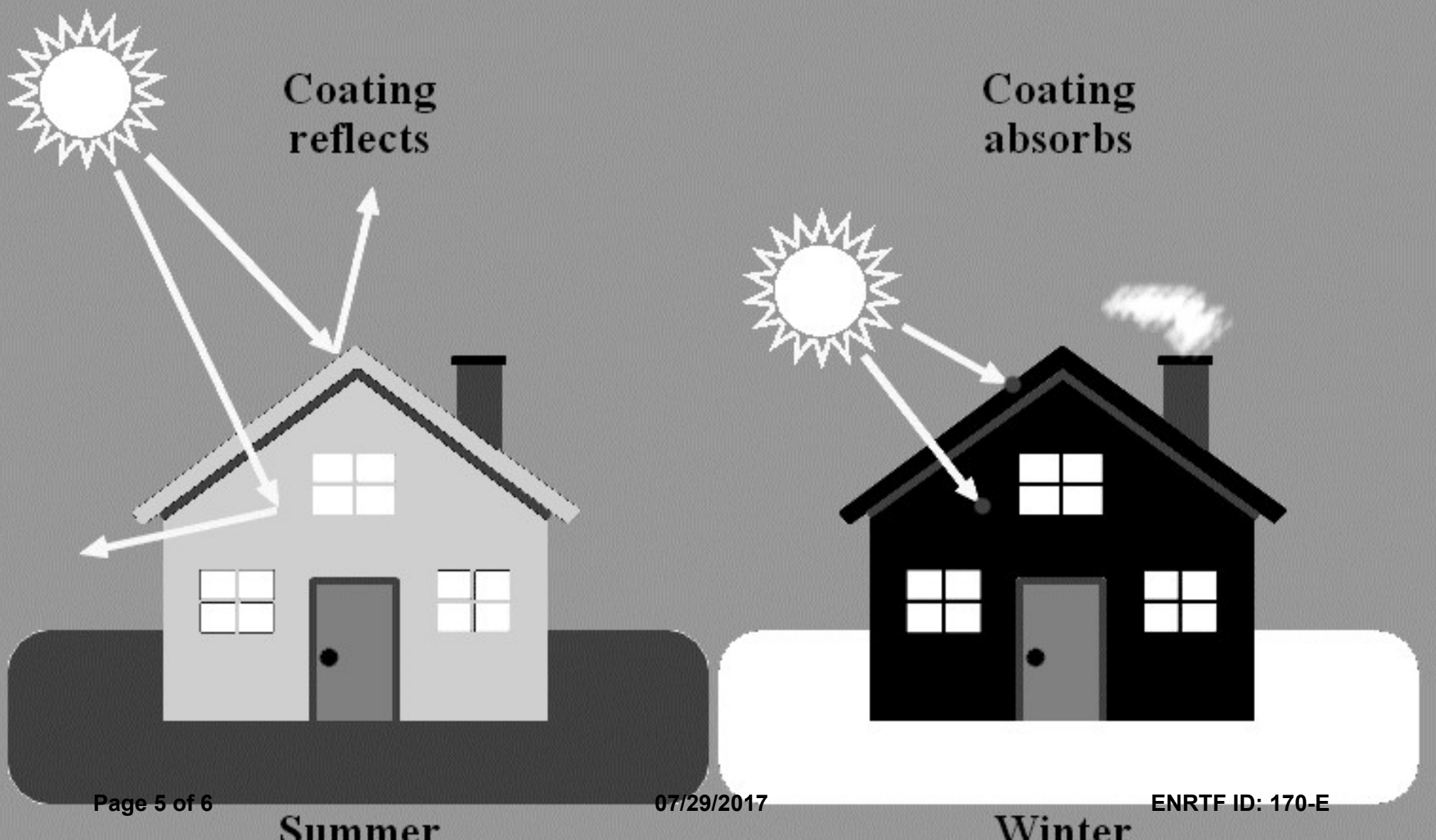
HOT COATING

Sunlight is reflected away.
Building stays cool.

COLD COATING

Sunlight is trapped inside.
Building stays warm.





Project Manager Qualifications and Organization Description

Project Manager: Dr. John E. Sinko
Dr. Sinko is an expert on optics and materials and teaches undergraduate and graduate coursework on physics, optics, and materials in the Department of Physics & Astronomy at St. Cloud State University (SCSU). He personally supervises 2 dedicated optics laboratories with 2750 ft^2 space in the SCSU Integrated Science and Engineering Laboratory Facility (ISELF). Dr. Sinko is strongly supportive of undergraduate research and frequently collaborates with other departments in research activities.

Education:
Ph.D. Physics, University of Alabama-Huntsville (5/2008)
M.S. Physics, University of Alabama-Huntsville (12/2005)
B.S. Mathematics and Chemistry, Furman University

Professional Experience:
St. Cloud State University, Assistant Professor, 2014-present
St. Cloud State University, Visiting Assistant Professor, 2012-2014
The Ohio State University-Newark, Visiting Assistant Professor, 2010-2011
Micro-Nano Global Center of Excellence/Nagoya, Researcher, 2008-2009
Kratos Defense & Security Solutions, Optical Engineer, 2008

Member Organizations: AAPT, AIAA, APS, OSA

Related Grant Activity:
- **Awarded**: 2014 SCSU New Researcher Award (as co-PI; PI: Dr. Kannan Sivaprakasam) "Development of Smart Materials for Solar Energy Conversion" ($7999.80)

Relevant Publications:
- **J. E. Sinko**, A. J. Corbett, T. L. Hislop, and M. E. Rupp, "Angle Dependence of Diffuse Reflectance for a Microencapsulated Thermochromic Coating," *MRS Advances* **2**(6), 369-374 (2017). https://doi.org/10.1557/adv.2017.1
- **J. Sinko,** M. Gaffney, R. Preusser, K. Sivaprakasam, T. Tran, and D. Flevaraki, "Diffuse Reflectance Study on Thermochromic Materials for Solar Infrared Switching" in Advanced Photonics 2016 (IPR, NOMA, Sensors, Networks, SPPCom, SOF), Vancouver, Canada, *OSA Technical Digest (online)*, NoW1D.4 (2016). https://doi.org/10.1364/NOMA.2016.NoW1D.4

Organization Description:
St. Cloud State University is a regional comprehensive university located on the banks of the Mississippi river in St. Cloud, Minnesota. Its annual enrollment in 2016 was 15,100 students. The school hosts a broad spectrum of engineering and natural science disciplines at both the undergraduate and graduate level. SCSU has committed significant internal resources to development of research infrastructure in ISELF including a wide array of materials science, physics, and engineering instrumentation, including a 1230 ft^2 imaging center with AFM/SEM/XRD and a similar thermal science space with LDS/LSC/TGA.