

# REMRSEC Overview

**P. Craig Taylor**  
**Colorado School of Mines**

Supported by

- National Science Foundation (DMR-0820518)
- State of Colorado
- Colorado School of Mines

With active participation of researchers at NREL



- We investigate the improbable, the fantastic, the futuristic, which quickly become routine.



## Uniqueness of the REMRSEC

### Unique with regard to MRSEC's

- Exclusively materials for renewable energy
- University driven collaboration with a national lab (NREL)
- Energy and Environment are central themes at CSM
- Heavy industrial Involvement

### Unique with regard to Other Energy Research Centers

- Student centric
- Workforce development
- Unique Science
  - Nano-dots of Si with unique absorbers

### Impact magnified by CSM size and technical focus

Small Focused University (200 tenure track faculty)

# 4 in physics BS degrees, Top 10 in materials Science and Chemical Engineering

# The Problem with Silicon Nanodots



Nanodot oxidation Movie.wmv

- New Hiring Paradigms
- New Postdoctoral Mentoring Paradigms
- Great Influence on Diversity
- Undergraduate Research Opportunities
  - Vibrant Program
  - Emphasis on Women and Minorities
- K-12 Teacher Training Workshops
- Dyslexic Workshop
- Energy Minor
- Bi-weekly Graduate Student Luncheons

- New Hiring Paradigms



- New Postdoctoral Mentoring Paradigms



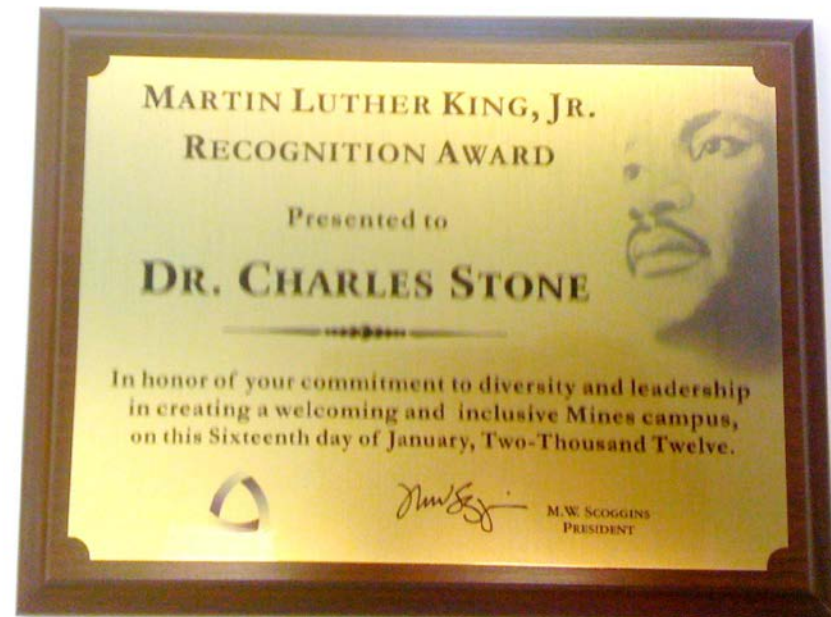


# Impact of MRSEC on Entire University

- Great Influence on Diversity  
2011 award to REMRSEC as  
a center



2012 award to Chuck Stone,  
the REMRSEC REU Director



- Undergraduate Research Opportunities
  - Vibrant Program
  - Emphasis on Women and Minorities



REU 2012 Group Photo. Back Row (L-R): Kevin Sanders, Violaine Salomon, Malcolm Davidson, David Bicknase, Nicholas Sather, James Ham, Matt Musselman, Kevin Boxer, William Leith, Myles Martinez, Terrell Fruit. Front Row (L-R) Erich Meinig, Tom Flores, Karl Brennan, Rachel Kurchin, Nicole Johnson, Charlotte Evans, Jose Cruz, Stephanie Gomez, Kelsey Kawaguchi, Kento Okamoto.

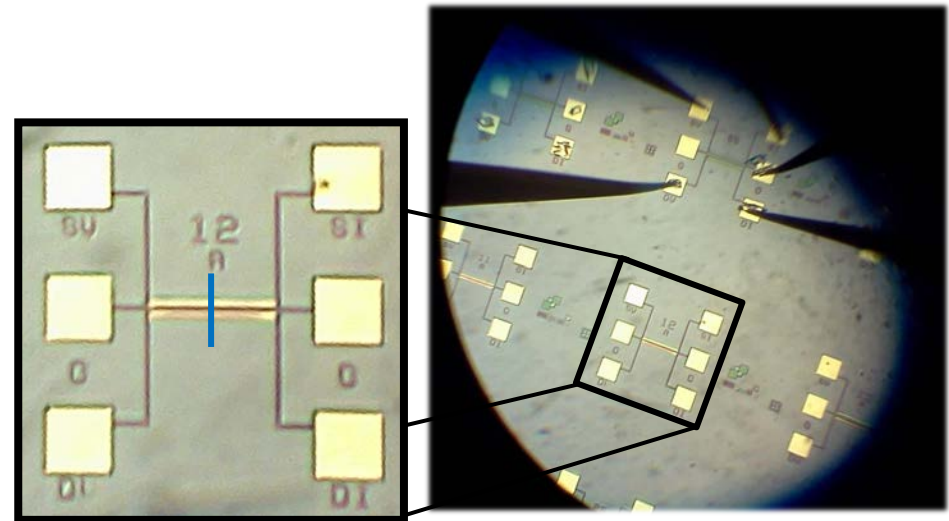




Terrell Fruit, REU student, presenting his 2011 Summer REU research at the National Society of Black Physicists / National Society of Hispanic Physicists Joint Conference in Austin, TX on September 22, 2011.

# REU Students: The Ionic Transistor

Former REU student Kory Risky won the title of 2010 Homecoming Queen at CSM



Kory Risky: “For me, the REU was an excellent opportunity to do hands-on research and to essentially be a ‘grad student’ for a summer. After the REU, I knew grad school was for me.”

- K-12 Teacher Training Workshops
- Dyslexic Workshop
- Bi-weekly Graduate Student Luncheons



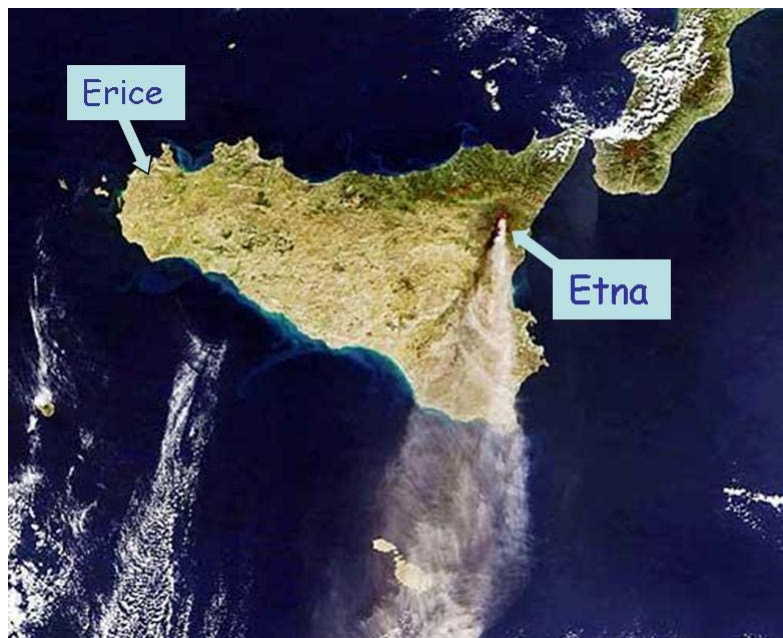


*"MATERIALS FOR RENEWABLE ENERGY"*

May 28th - June 2, 2010

*"ENERGY HARVESTING AT MICRO AND NANOSCALES"*

July 23-27, 2012.





## 4 REMRSEC post doctoral/research fellows have (or will) complete their appointments

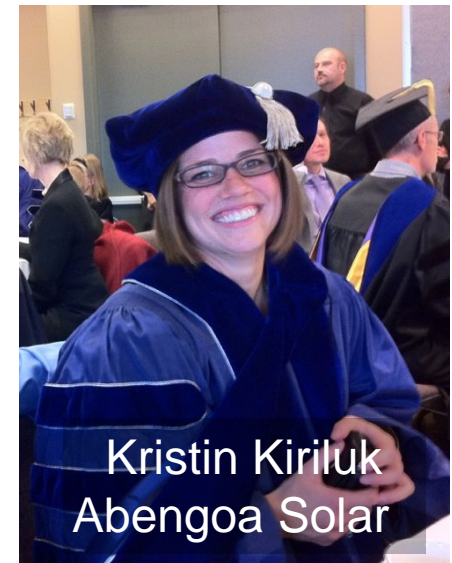
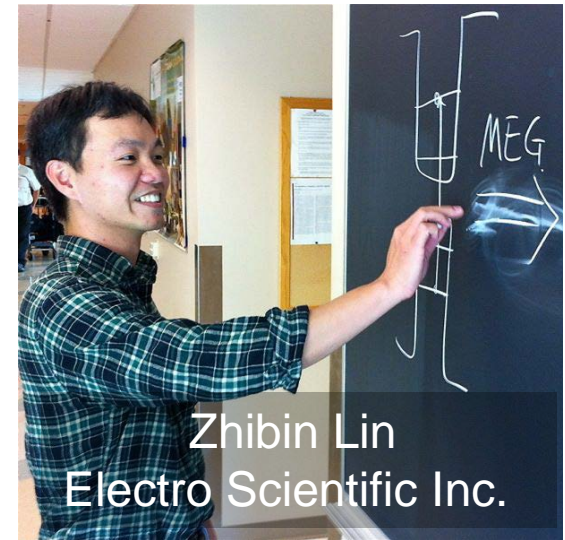
- Positions: 1 industrial, 1 journal editor, 1 national res. inst. (India), 1 post doc

## 7 REMRSEC grad fellows and affiliated grad fellows have received their PhDs

- Positions: 4 industrial, 1 university lab, 2 REMRSEC post docs (actively interviewing)
- Companies: Abengoa Solar, Lam Research, Motech Solar, Ocean Thin Films

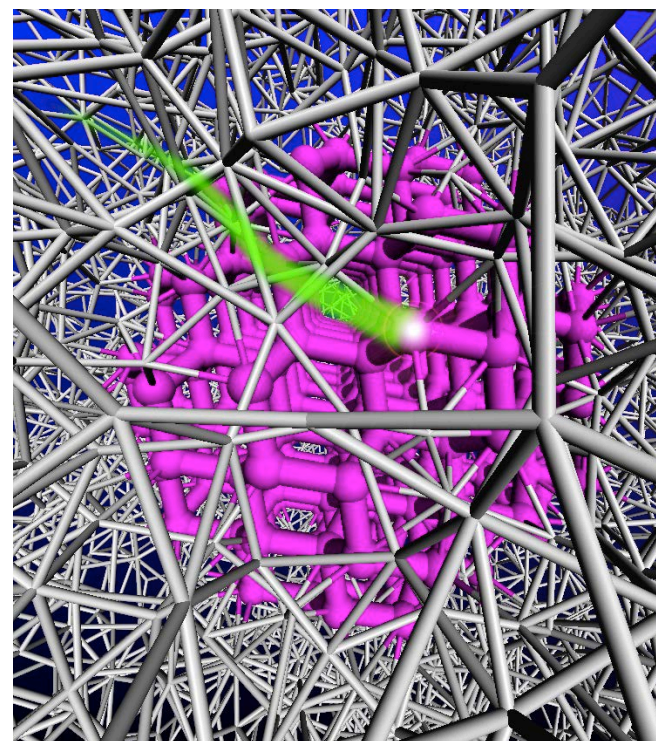
## 4 REMRSEC MS students graduated

- 3 continued on to PhDs, 1 employed at Seagate

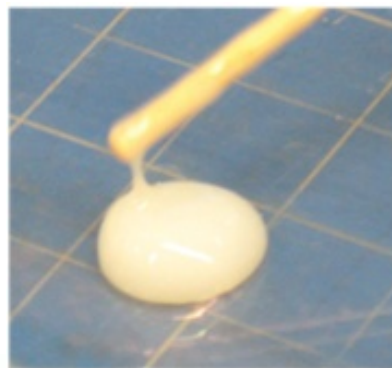


- Rapid Transfer of Basic Science to Applied Research
  - Nanocrystalline Si to DOE Project
  - Polymeric membrane Transferred to 3M
  - Ceramic Proton Conductor Transferred to Coors Tech
  - Center for Revolutionary Solar Photoconversion
  - National Renewable Energy Laboratory

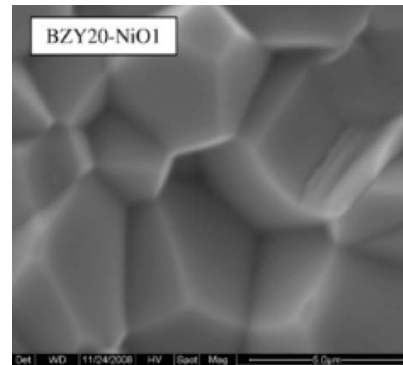
Nanocrystalline Si  
to DOE Project



Polymeric membrane  
Transferred to 3M



## Ceramic Proton Conductor Transferred to Coors Tech



## Center for Revolutionary Solar Photoconversion



## National Renewable Energy Laboratory





## ITN Energy Systems Littleton CO

### Spinoffs



1996 Global Solar

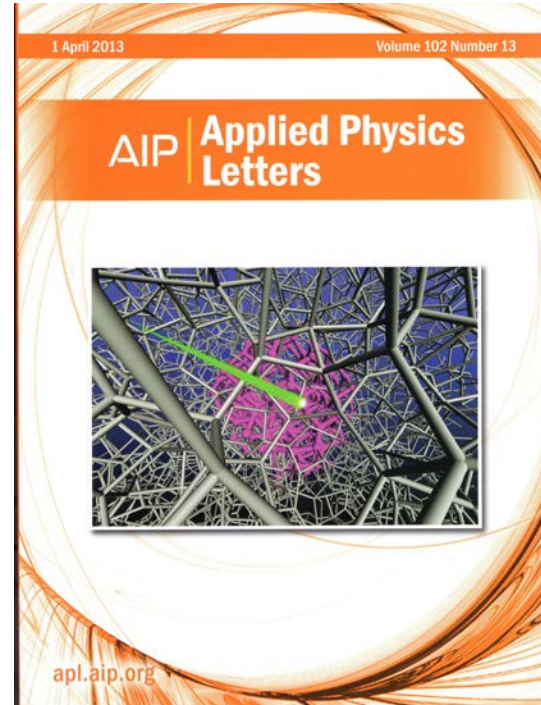
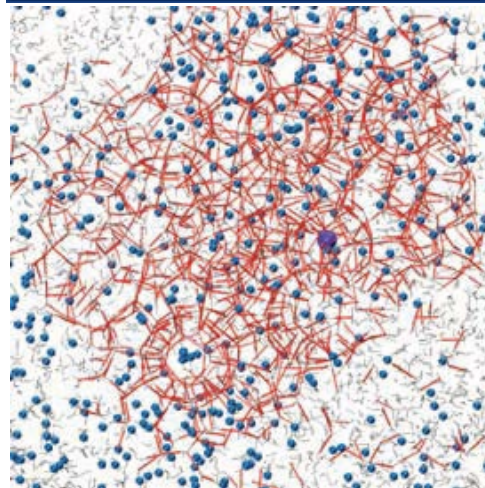


2005 Ascent Solar

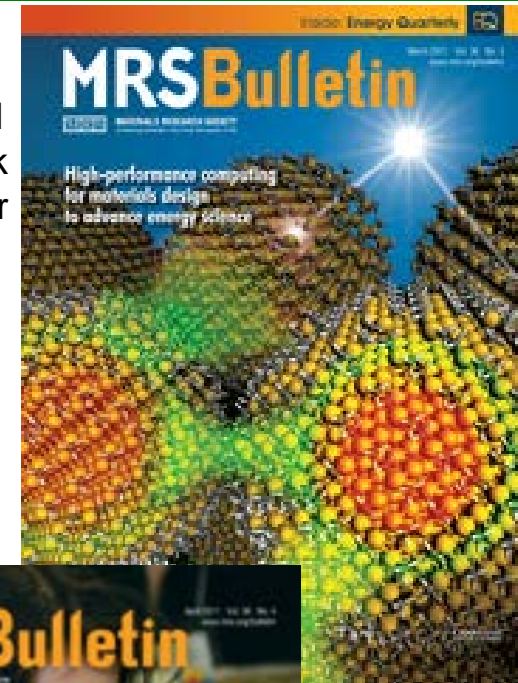
<b>Google Search Term</b>	<b>Position on Page 1</b>
• Renewable Energy Materials (Research) – (NREL is 2 or (4))	1 (1)
• Advanced Membrane Research	1
• Next Generation Photovoltaics – (only UNC EFRC above us)	6
• Undergraduate Renewable Energy Research – (below U. Wisconsin library)	2
• Energy Minor – (behind MIT, followed by Berkeley, GMU, Cornell, UNLV, ...)	2

# High Impact in Professional Societies

## Materials Research Society as an example

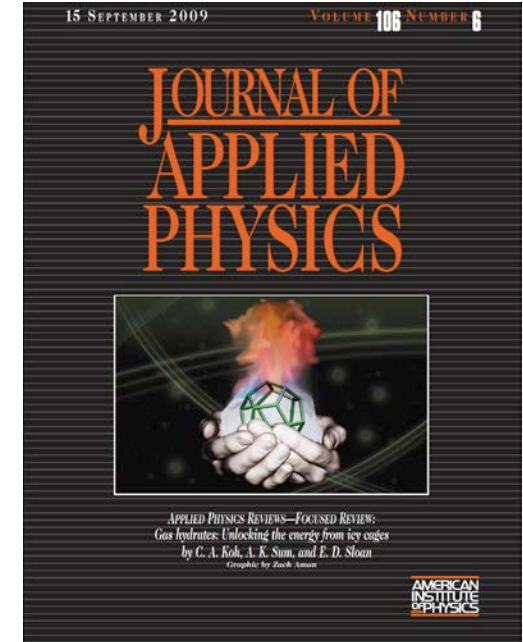


March 2011  
Mark Lusk  
Co-Editor



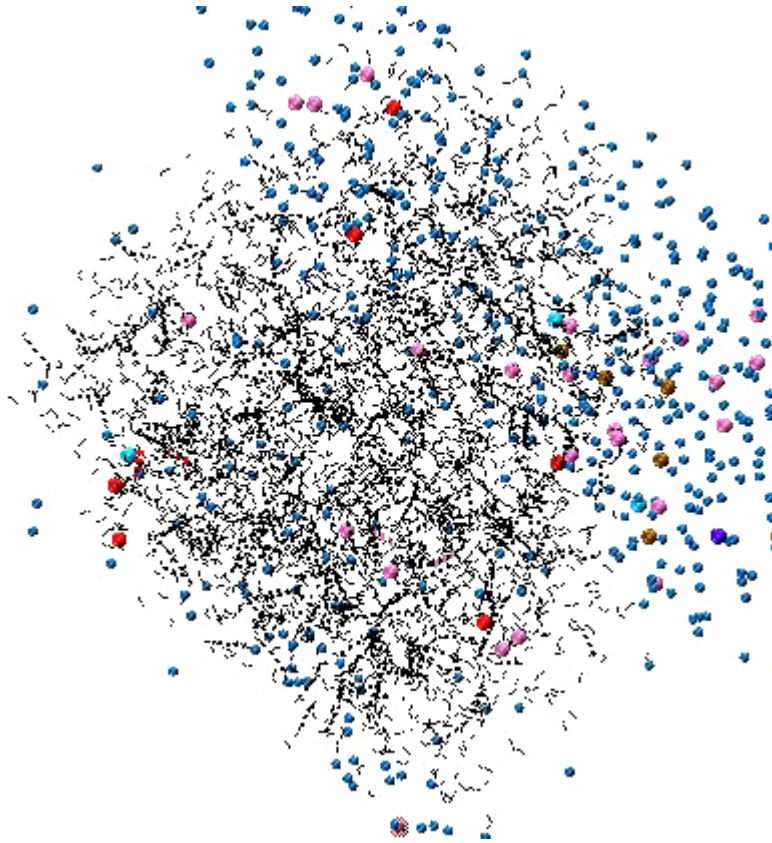
April 2011  
Barb Moskal  
Co-Editor

# Cover Articles on Energy Storage in Clathrates





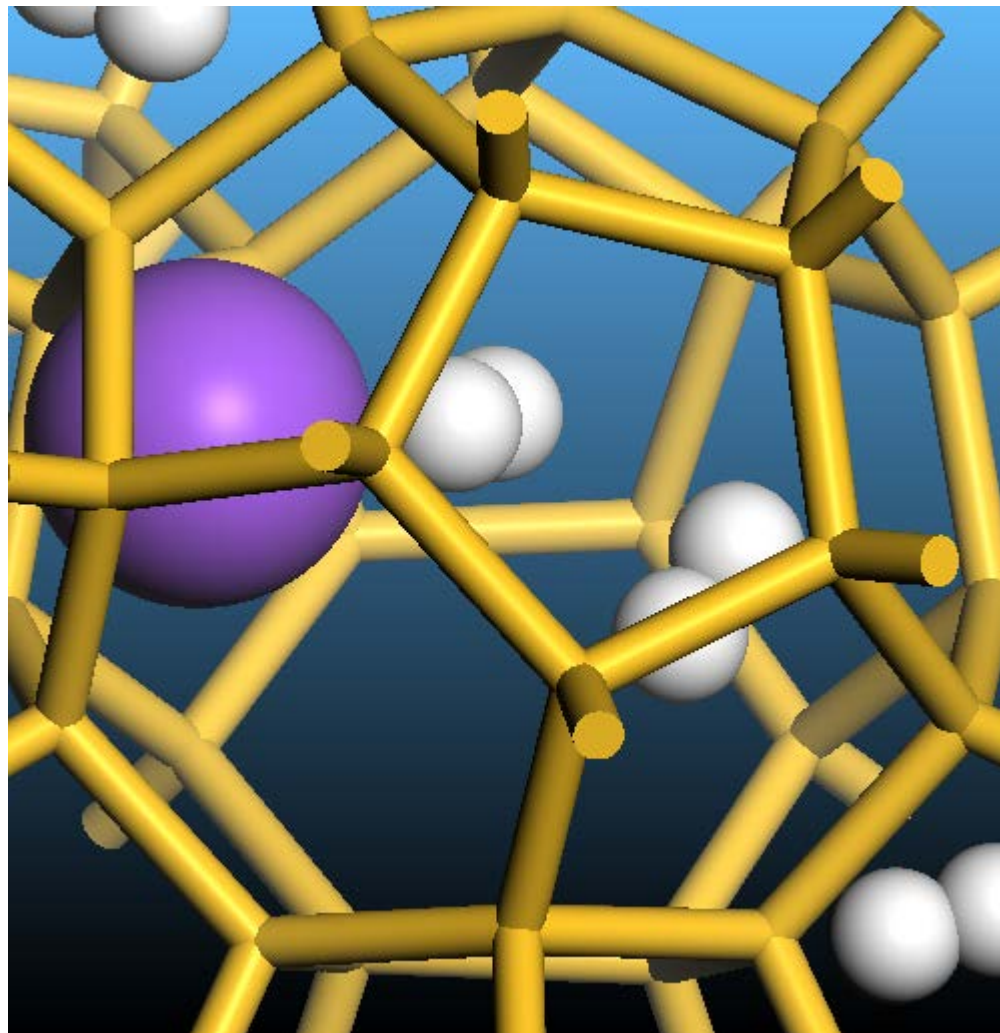
# Seeds Spawn New Transformative Programs



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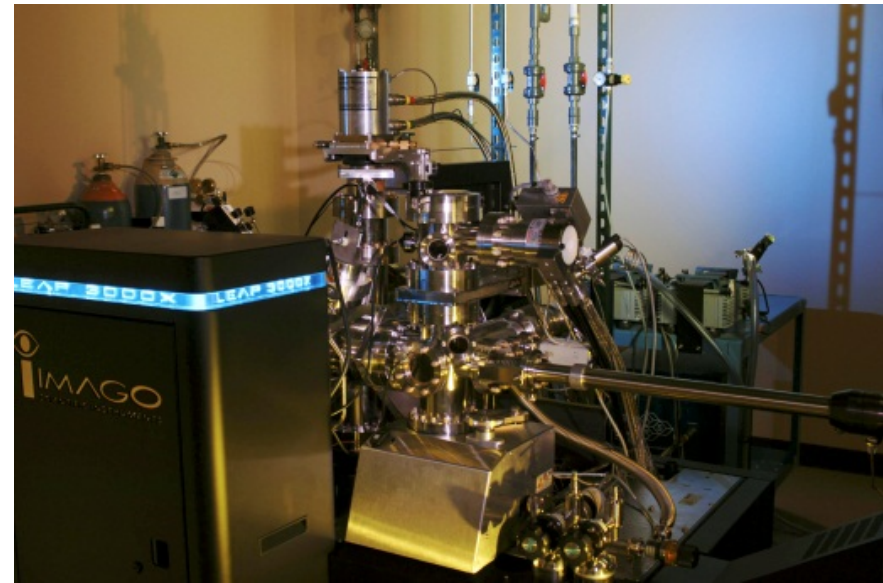
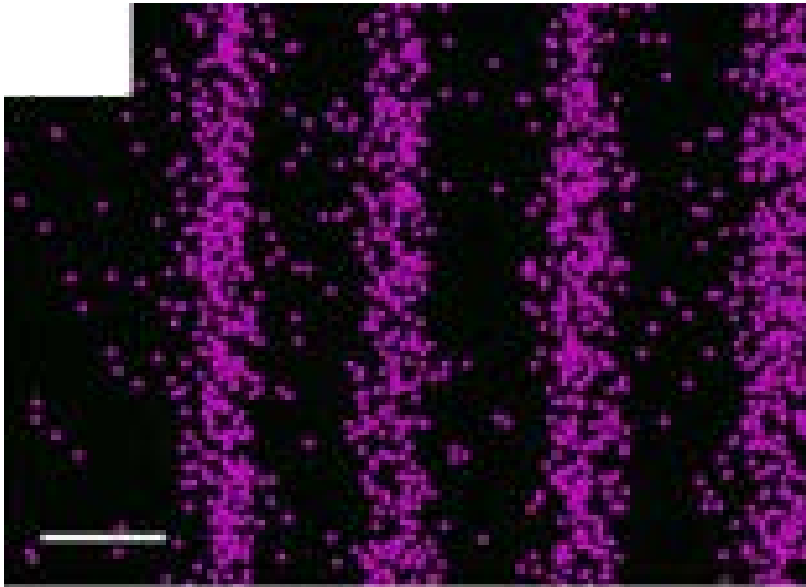
## Molecular Hydrogen Stored in Clathrate Si

- Structure nucleates around Na atoms
- Storage is reversible



Video courtesy of Mark Lusk

## Atom Probe Laboratory



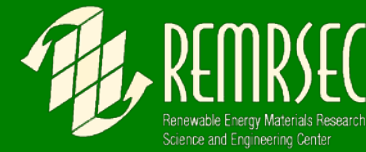
# Final Word

- **We Make a Difference**
  - Throughout the university and the region
- **We are Unique**
  - Exclusively materials for renewable energy
  - University driven collaboration with NREL
  - Small institution
  - Heavy student and post doc involvement
- **We are the Place to Be**
  - For transformative research on materials for renewable energy applications





# Selected Grants Leveraged by REMRSEC



Funding Organization	Amount	Duration (years)	PI
Cima Nanotech	\$ 65,124	0.5	Beach
Science Foundation Ireland	\$ 79,861	1	Wolden
Eindhoven University	\$ 140,000	5	Agarwal
National Science Foundation	\$ 140,000	2	Wolden
National Science Foundation	\$ 310,000	3	Wolden
DOE Sunshot	\$ 1,484,364	4	Collins
DOD (Army MURI)	\$ 2,500,000	5	Herring
National Science Foundation	\$ 390,000	3	Stone
DOE EFRC	\$ 550,000	5	Taylor
DOE NREL	\$ 550,000	4	Taylor

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Total \$ 6,209,349

REMRSEC NSF funding to date: \$ 4.8 M (\$ 9.6 M over six years)

CHECRA Funding to date \$ 1.6 M (\$ 2.4 M over six years)

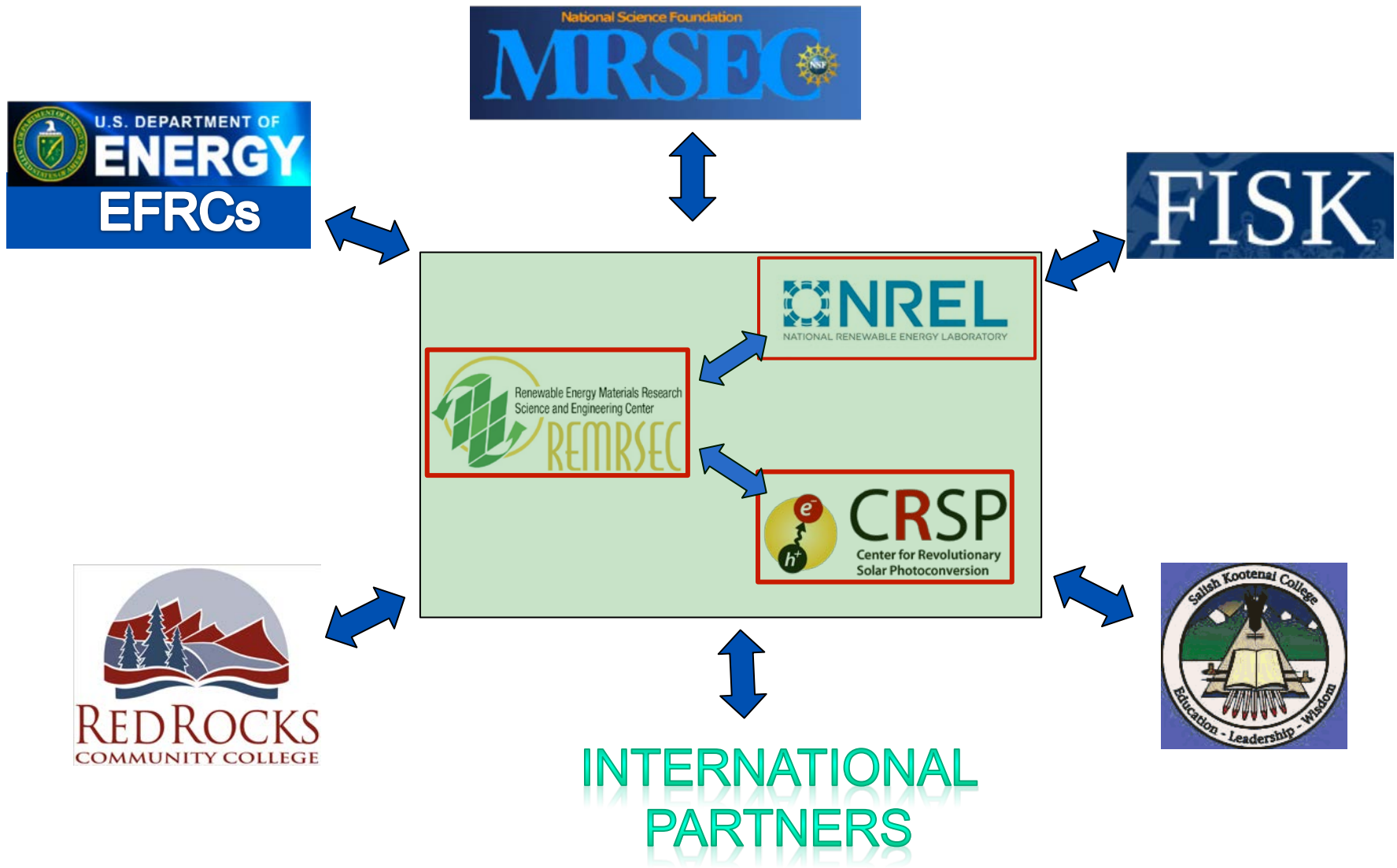
Indirect Cost Return to date \$ 1.0 M (\$ 1.4 M over six years expected)

**Leveraged funding used to combat difficulties with flat NSF funding**

Internationally visible NSF supported MRSEC directed at fundamental materials research, education, and outreach in renewable energy.



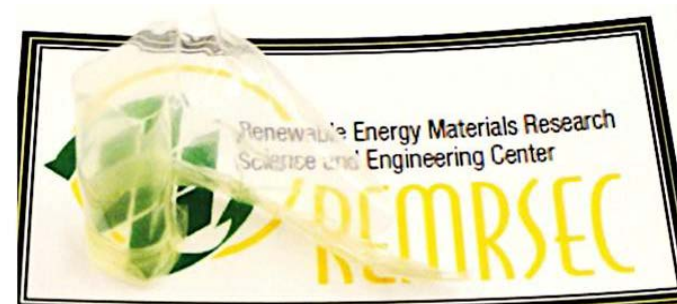
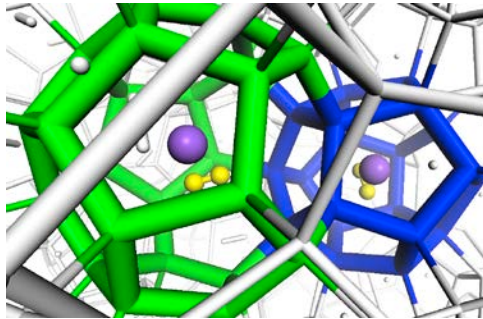
# REMRSEC Partnerships: Collaborative





# Transfer of basic discoveries

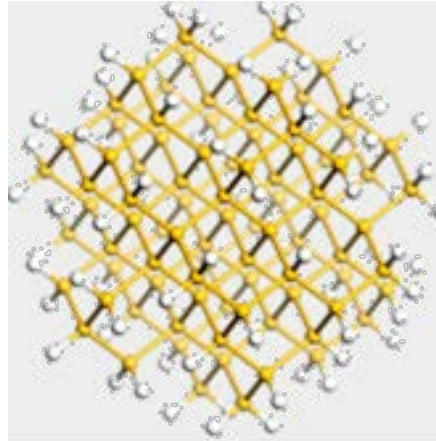
- Clathrates for Renewable Energy Applications
- Membrane Durability Characterization



# IRG1: Materials for Next Generation Photovoltaics

**Vision: Innovation in silicon-based nanostructures can drive a paradigm shift in solar energy conversion**

- Vision not accomplished by incremental changes in materials
- Transformative results through excitation and relaxation by design and new nanostructural architectures



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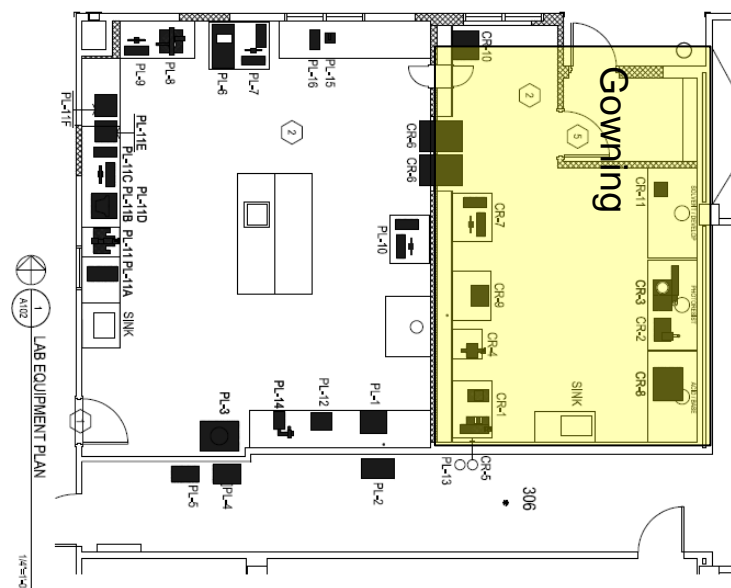
Emergence of a new paradigm for quantum confined PV made possible by the expertise, tight collaboration, and facilities of the Center.

# Hill Hall – new facilities



## Synthesis Lab

- HH323
- ~1000 ft<sup>2</sup>
- 8 fume hoods
- organic synthesis
- dry glove box
- O<sub>2</sub> free glove box
- nanoparticle area

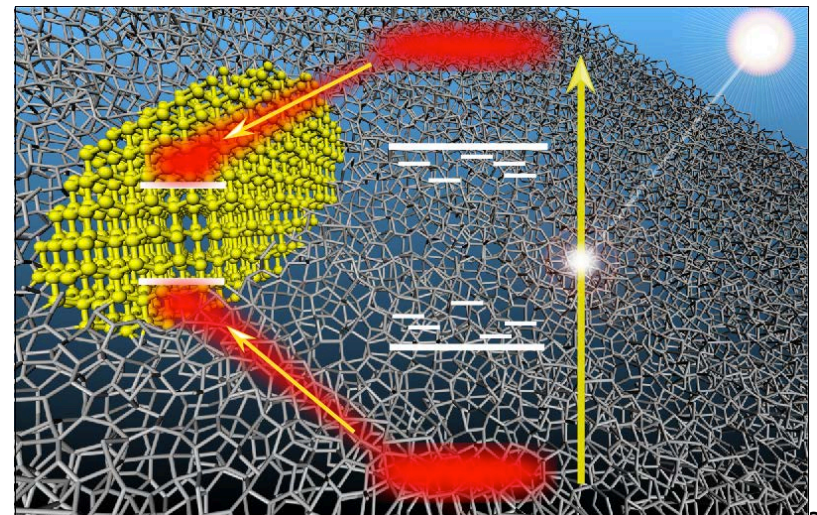


## Clean Room and Processing Lab

- HH310-312
- ~1000 ft<sup>2</sup>
- class 1000 clean room
- processing equipment

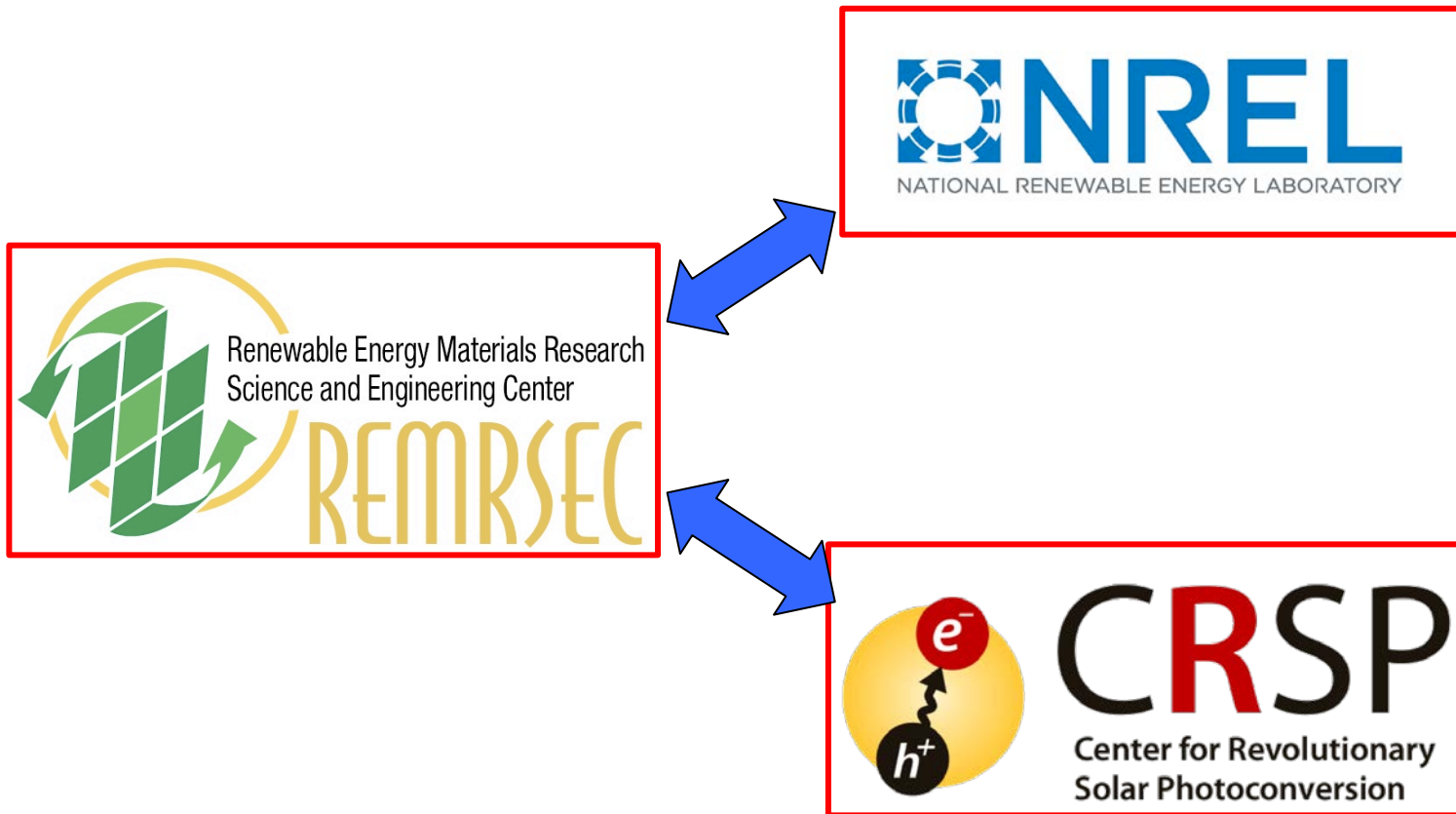
## Research

- IRG1: Materials for Future Generations of Photovoltaics
- IRG2: Advanced Membranes for Energy Applications
- Seed program: New Research Directions; Emphasis on Junior Faculty
- Active NREL participation
- Strong Industrial Outreach
- Active International Collaborations



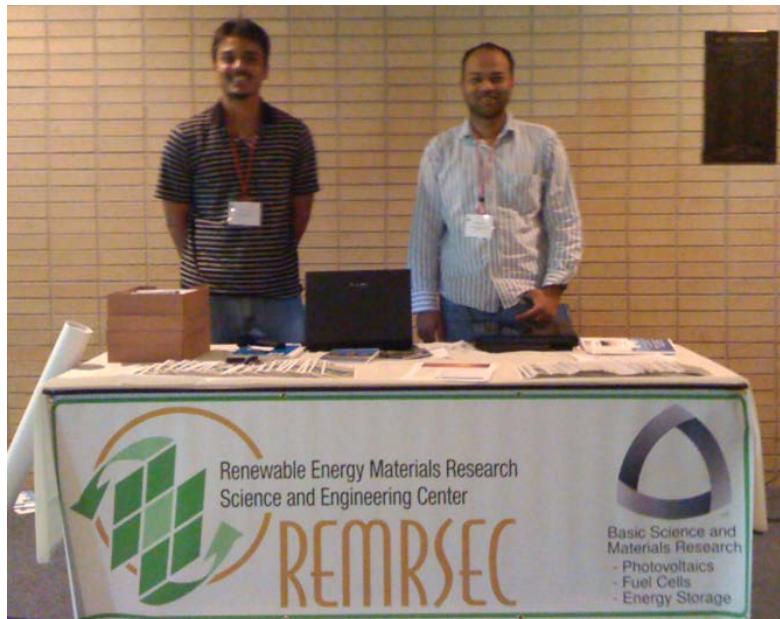


# REMRSEC Partnerships: Strategic



## Human Resource Development

- Vibrant REU Emphasizing Renewable Energy Research
- Teacher Workshop Bringing Renewable Energy Concepts in Classrooms
- Campus-wide Effect on Diversity
- Joint Hires with NREL
- Campus-wide Postdoctoral Mentoring Program



External Advisory Board visits and conference calls

Executive Committee Meetings

Seed grants

Teacher training workshops

REU

Diversity



## Industrial Collaborations

- **Center for Revolutionary Solar Photoconversion (CRSP)**

  - Major industrial outreach effort

  - Joint annual meeting

  - Rapid transfer of transformative results from REMRSEC research

  - Coordinated REMRSEC and CRSP management structures

    - REMRSEC Industrial Coordinator is CRSP Managing Director

    - REMRSEC Director was CRSP Scientific Director

- **Current CRSP Member Companies**

  - Abengoa Solar PV Inc.

  - Sharp Corporation

  - Tokyo Electron

  - General Motors

  - Total



**CRSP**

Center for Revolutionary  
Solar Photoconversion



**Cutting Edge Research**

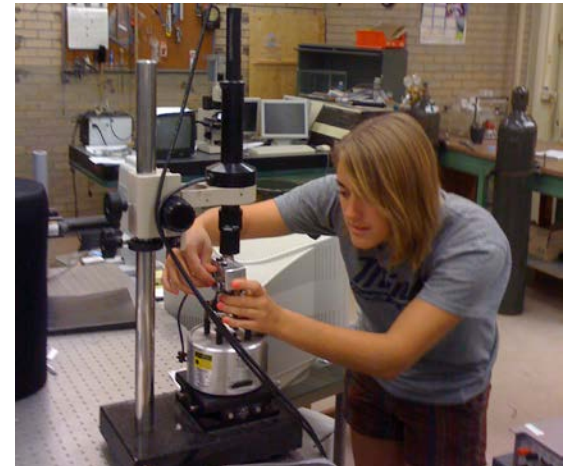
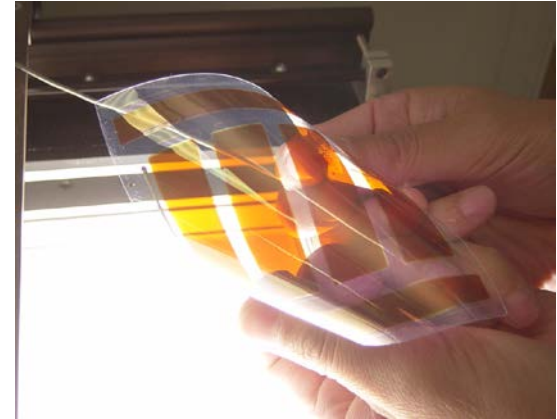
**Human Resource Development**

**Strategic Partnerships**

**Unique Facilities**

**Attention to Diversity**

**Continuous and Critical Assessment**



# Impact magnified by CSM size and technical focus

- Energy Minor
- Minergy Club
- Diversity Across Campus
- Recruiting at all levels across campus
- Shared Facilities
- Postdoctoral Mentoring
- Influence on Undergraduate and Graduate Research beyond the REMRSEC
- Graduate Student Led Bi-Weekly Lunch Meetings



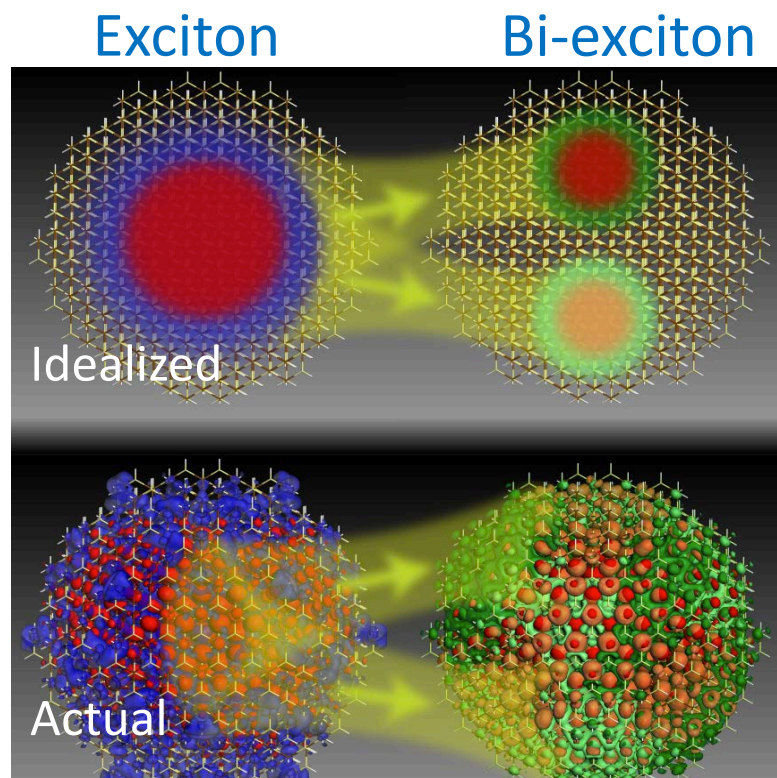
# Multiple Exciton Generation Rate in CdSe Quantum Dots

## Why is this Important?

- Helped resolve long-standing controversy
- Guide new material designs
- CSM-NREL collaboration
- Highly publicized
- Extended to other materials (e.g. Si)

*"These results are exciting because they go far towards resolving a long-standing debate within the field. Equally important, they will contribute to establishment of new design techniques that can be used to make more efficient solar cells."*

--Mary Galvin, Program Director, NSF DMR



Z. Lin, A. Franceschetti, and M. Lusk,  
ACS Nano, 2011



# Honors and Awards Continued

## CSM

- Highest Starting Salaries of any engineering school
- #10 in Forbes list of top 20 colleges for women in STEM
- BS degrees: #5 among physics, #10 among Chemical Engineering, #10 among Materials Science departments

## Women engineer a change

Female students on rise at CSU, Mines in a field once dominated by men



Colorado School of Mines student Jasmine Sanchez, between Tyler Bush, left, and Alex Mati, has the answer to an electricity and magnetism problem in a physics class Wednesday. Mines has among the highest percentage of female engineering students. Karl Gehring, The Denver Post

## 12 Colleges Whose Payoff In Pay Beats Harvard's

By ALAN FARNHAM  
Sept. 20, 2012



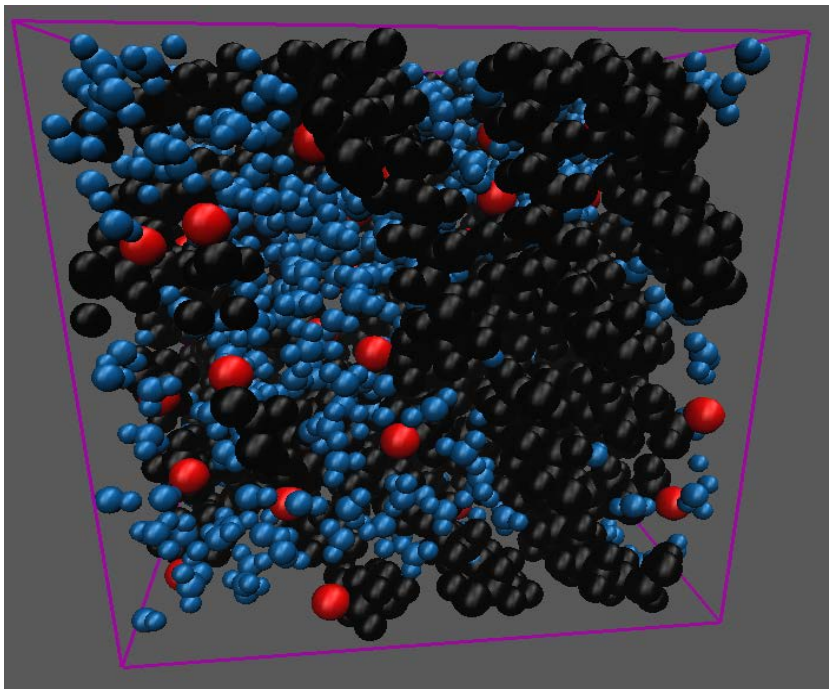
“...graduates of the Colorado School of Mines earn a starting median salary of \$63,400. ... The cost of tuition and fees is only \$17,718 for in-staters; \$32,748 for out-of-staters.”





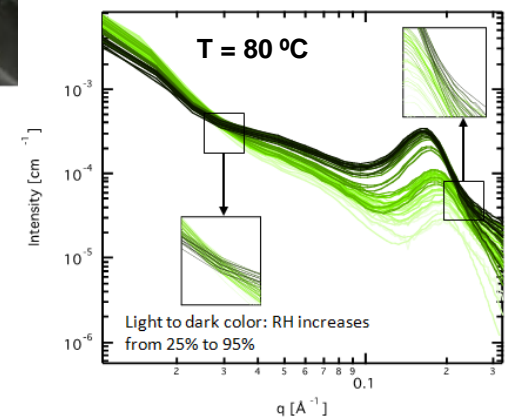
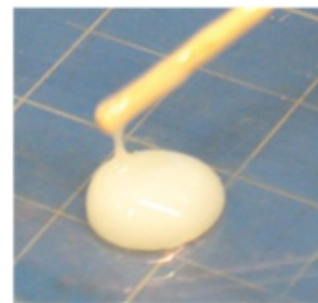
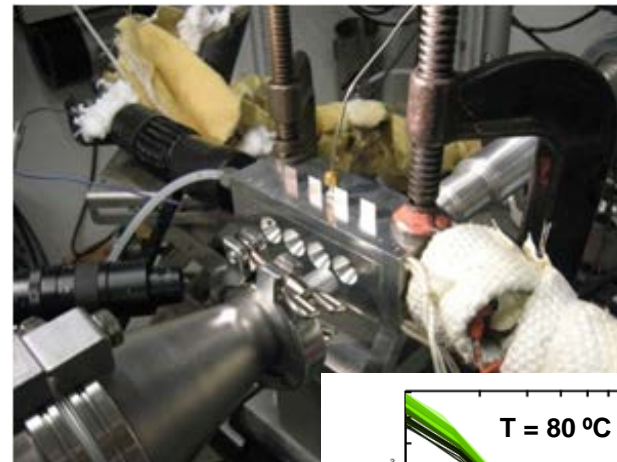
## State-of-the-art tools for simulation, characterization Polymers by design

### Multi-State Empirical Valence Bond



Snapshot of 3M membrane

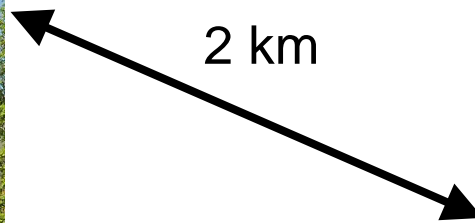
### Dynamic SAXS/New Ionomers



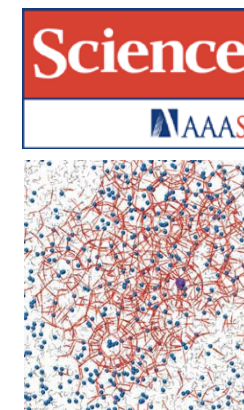
Schlichting et al., *Macromol.* **45**, 3874, (2012).  
Yuan et al., *Macromol.* **in press**, (2012).

# Why a Renewable Energy Center Here?

- Energy and the Environment are central themes at CSM
- Internationally recognized scientists and engineers in renewable energy
- Coupling with key scientists from NREL creates a unique team with unique opportunities for graduate students
- Collaborations enhanced by close proximity
- Coupling with industrially funded center facilitates research transfer
- #10 in Forbes list of top 20 colleges for women in STEM
- BS degrees: #5 among Physics, #10 among Chemical Engineering, #10 among Materials Science departments



- **Research**
  - Address problems of critical importance
  - (PV materials, membranes, storage)
- **Partnerships**
  - NREL
  - Industry
  - International world leaders
- **Human Resources**
  - Undergraduate, Graduate, Post Doc Training
  - K-12 Teacher workshops
  - Hiring
- **Facilities**
  - Integrated clean room, processing and synthesis labs
  - Associated atom probes
- **Diversity**
  - New paradigms for hiring
  - Campus wide influence
  - Coupling with minority serving institutions
- **Assessment of all programs**



## Company

- 3M
- United Solar Ovonic
- MVSsystems
- ITN Energy Systems
- PrimeStar Solar
- Lifeloc
- Luna Innovations, Inc.
- SiCSystems
- Coors Tek
- Physical Optics Corp.

## Nature of Collaboration

Membranes

Nanocrystalline Si

PECVD

Plasmonics

CdTe

Organics, Detection

Organic PV

SiC

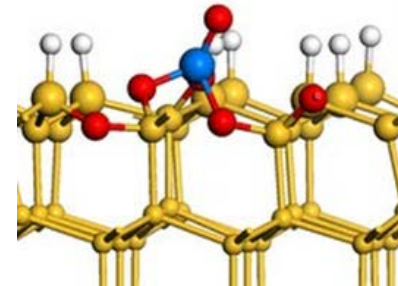
Ceramics

Spectroscopy



# A New Look at Silicon Oxidation

- H - passivated Si surface provides no barrier to the first oxidation event
- Organic ligands give greater protection - oxygen interacts with ligands first
- Small Si dots (<1nm) are vulnerable at apex, ridge, etc. sites
- If defects are present, all bets are off, they open the surface to rapid attack



## Why is this important?

- Density of surface defects drops with dot size
- There may be a Goldilocks size between 1-2nm diameter with optimal resistance to oxidation
- Theory driving experiment



Li, et al., *J. Chem. Phys.* **136**, 064507 (2012)

Li et al., *ACS Nano*, accepted.

