Report on the
NINE Curriculum and Education Workshop
June 11-13, 2007

National
Institute for
Nano
Engineering

A Government/University/Industry Partnership to
Develop the Next Generation of Innovators and Innovations
for the field of Nano Engineering

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Executive Summary

"Rising Above the Gathering Storm", a recent study by the National Academy of Sciences and the National Academy of Engineering, together with several other similar studies, documents the growing concern that the U.S. is losing its longstanding global technical leadership position. In addition these studies found that it is becoming increasingly difficult to attract the best and brightest U.S. students to science and engineering fields, threatening the very foundation of the U.S.'s technology-based economic competitiveness.

Motivated by these concerns and the need for immediate action, Sandia National Laboratories, together with leading university and industry institutions, formed the National Institute for Nano Engineering (NINE). Its goal is to develop and enable the next generation of world-leading innovators and their innovations in the opportunity-rich field of nano engineering. NINE's founding partners include twelve major U.S. research universities, six high profile U.S. businesses, and Sandia National Laboratories.
On June 11-13, 2007 NINE held a curriculum and education workshop in Albuquerque, NM. The purpose of the meeting was to discuss educational approaches and plans for creating an integrated nano engineering program that will effectively attract, inspire and enable a new generation of U.S. innovation leaders who will create new nano-engineering-based solutions to important national problems.

At this meeting more than 50 participants from 15 government, universities, and industry institutions discussed approaches, organizational structures, and policies that could help to achieve the identified NINE goals together with the basic question of whether NINE can make a unique contribution to the nation in this area.

Comments from workshop participants included the following:

- The power of NINE is integration, with Sandia and its unique facilities and capabilities as the hub connecting and collaborating with a network of strong research universities and value-driven industry partners. This network can provide a unique opportunity for students and can be a vehicle for attracting top students into science, engineering and math. Its scale, strong partners and exciting projects can create the critical mass needed to produce successful, innovative students.

- Sandia's facilities are unique in combination and provide the ability to produce prototype nano-micro technology systems involving multiple facilities and capabilities, a difficult opportunity for universities to provide their students.

- Although NINE cannot immediately increase the total number of U.S. engineers, it can significantly affect U.S. nanotech leadership by focusing on the "best and brightest" students, giving them opportunities to be part of large multidisciplinary project teams working collaboratively on innovative solutions to important national problems. These unique opportunities will prepare them to succeed in national leadership roles in nano engineering.

- NINE's vision for combining multidisciplinary nanotechnology curriculum innovation and exciting work at partner institutions with world-class mentors,

cross-disciplinary teams, exposure to real world business issues, and an understanding of the impact of technology on society, is unique.

At this workshop participants agreed that NINE will be organized around three elements: (1) Enrich Technical Education, (2) Provide access to State-of-the-Art Capabilities, and (3) Inspire Translation of Ideas to Reality.

The operational plan for NINE calls for curriculum development to be led by university partners, access to leading edge facilities to be provided by Sandia, and for researchers from all partners to work with and mentor students as part of NINE-funded projects. These projects will focus on innovative pre-competitive research in areas of interest to the nation and the NINE industry partners. Industry partners will provide guidance in selecting valuable projects, funding for projects, and industry internship opportunities for students at their facilities. In addition to providing access to facilities, Sandia will serve as the administrative hub and the primary location for NINE student internships. NINE technical projects and administrative expenses this year total about $7.5M.

The current technical theme areas of NINE are Nanoelectronics and Quantum Information Processing, Nanotechnologies for Energy, and Nanosynthesis and Nanomanufacturing. These were chosen based on the differentiating technical strengths and facilities of the NINE partners.

After discussions throughout the workshop, the participants provided feedback and guidance on the NINE structure, operations and approach and agreed to continue to work together to implement the NINE vision. This will specifically include preparation of a proposal to the DOE-Office of Science for NINE to be become a Discovery Science and Engineering Innovation Institute.

Report on the NINE Curriculum and Education Workshop - June 11-13, 2007

Regan Stinnett, Bob Hwang, and Justine Johannes
Sandia National Laboratories
August 22, 2007

The National Institute for Nano Engineering (NINE) held a curriculum and education workshop on June 11-13, 2007 in Albuquerque, NM. The purpose of the meeting was to discuss educational approaches and plans for creating a NINE program that will effectively support the development of a new generation of U.S. innovators who will create new nano-engineering-based solutions to important national problems.

Background and Objectives

A previous NINE partner meeting was held on October 25, 2006 to develop the goals and objectives for Discovery Science and Engineering Innovation Institutes (DESII), using Sandia's NINE as a model. An outcome from this meeting was a Memorandum of Understanding (MOU) that articulates the goals and objectives of NINE along with the roles and responsibilities of the various partner institutions. The following goals were identified as critical for a successful DSEII:

- Graduates educated with the breadth and depth to address critical national challenges and meet the needs of industry to drive innovation from concept to product,
- Graduates knowledgeable about teaming with scientists and engineers from other disciplines as well as business people, and
- Increase the quantity and quality of innovative engineers and scientists working to solve nationally important challenges.

The approach recommended for accomplishing DSEII goals included:

- New curriculum and novel learning opportunities through a national network of universities,
- Access to unique, large national laboratory facilities through research staff advisors/mentors
- Multidisciplinary, multi-institutional research programs that emphasize the latest engineering tools and collaborative environment approaches, and
- National outreach to stimulate interest and engagement in science, technology and engineering with teachers and students (K-12 focus).

This NINE Curriculum and Education workshop was held to follow-up in more detail on the ideas generated at the October meeting.

Meeting Structure and Goals:

The purpose of this workshop was to give the NINE university partners the opportunity to discuss specific approaches used at their institutions to educate nano engineers as well as to have the entire group discuss approaches, organizational structures, and policies that could help to achieve the identified NINE goals. A primary goal of NINE is to create a new generation of nano-engineering innovators and to enable them to create innovations that will help to solve important national problems and also help U.S. industry maintain

its global technology leadership position as a foundation for future U.S. economic competitiveness.

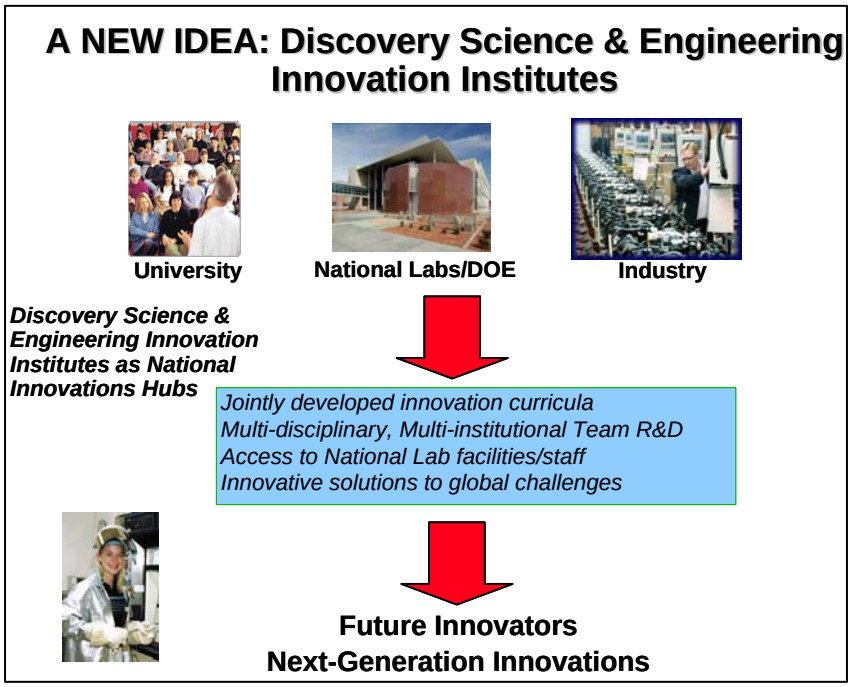
Questions that were intended to be central to the discussion included (1) how to provide additional breadth in already-crowded curricula without losing the depth of knowledge needed for success and (2) how to effectively provide new opportunities for students to work with top researchers in leading edge facilities as part of high performing multidisciplinary teams.

Partners attending included representatives from Harvard University, Harvey Mudd College, Massachusetts Institute of Technology, Notre Dame University, Rensselaer Polytechnic Institute, University of California-Davis, University of Florida, University of Illinois, University of New Mexico, University of Texas at Austin, University of Wisconsin, Yale University, Exxon Mobil Corporation, and Intel Corporation. A complete attendee list for the workshop is provided in Appendix A.

Meeting Chronology

The workshop began with a dinner on Monday night during which Duane Dimos, the Sandia Director leading NINE, provided an update on progress in growing NINE, including new NINE nano-engineering projects and infrastructure. These projects are already providing opportunities for 23 student researchers from our NINE partner universities to work with Sandia mentors, using world-class Sandia facilities, to create solutions to problems of interest to DOE and the nation.

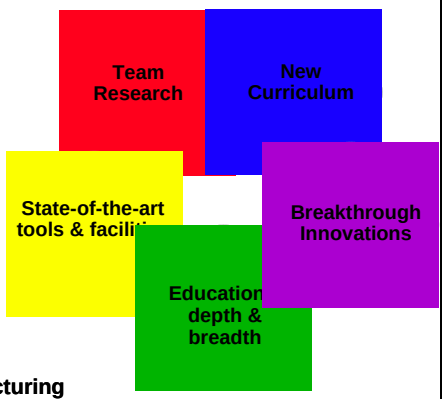
On Tuesday morning Bob Hwang presented a strawman model for NINE structure and operations for comment and modification by the NINE partners. The elements included the basic Government/University/Industry alliance, an operations model, and a diagram of NINE functions as represented by three elements: Enrich Technical Education, Provide Access to State-of-the-Art Capabilities and Inspire Translation of Ideas to Reality. Bob's complete presentation is available on the password protected "Partners" web page on the NINE web site: http://www.sandia.gov/NINE. The following figures from his presentation illustrate his key points:



NINE : A partnership to improve the quantity & quality of nano-engineers capable of addressing the most challenging national issues

Candidate Application Areas:

- **Reducing fossil fuel reliance**
- **Meeting national security needs**
- **Revitalizing the information revolution**
- **Improving our critical infrastructure**
- **Revolutionizing health care and delivery**
- **Taking the terror out of terrorism**
- **Global intelligence**
- **Sustaining the environment**
- **Economic security**
- **Avoiding technological surprise**



Nano-Engineering Theme Areas:

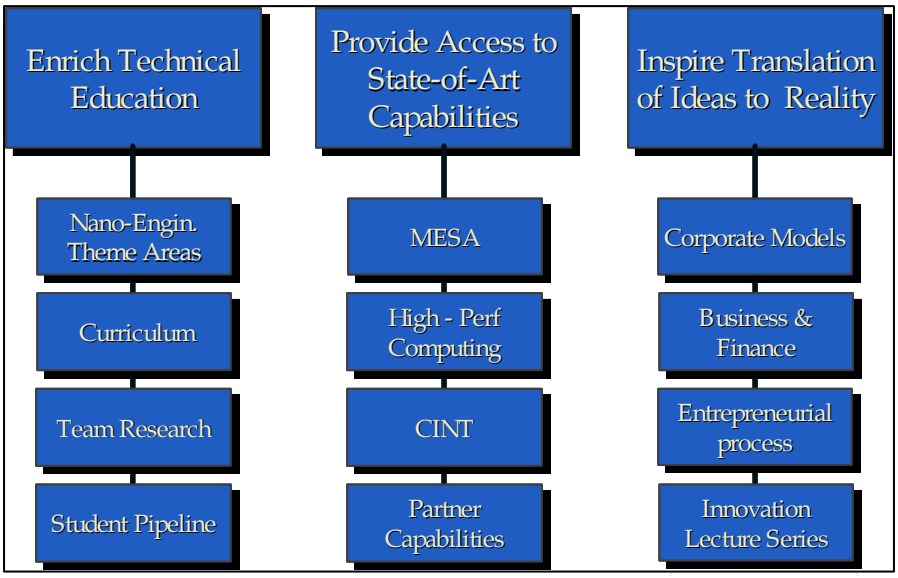
Nanomaterials Synthesis and Manufacturing
Energy Nanotechnologies
Nanoelectronics & Quantum Information Processing

Strawman NINE Operating Model

- **Executive Board & advisory committee**
- Students
- Graduate student fellowships – NINE certificate w/ degree
- Undergraduate internships – NINE certificate w/degree

- **NINE University Partners**
- Lead development & implementation NINE curricula - Directly funded
- Advocates and drivers for NINE
- Members of Target Area teams
- Sponsor and support NINE students

- **NINE Industry Partners**
- Advocates and Drivers for NINE
- Members of Target Area teams
- Development & implementation NINE curricula, mentoring
- Direct and in-kind funding



Bob's presentation was followed by presentations from the NINE partners on educational approaches and projects relevant to NINE at their institutions.

As part of pre-workshop preparation, all partners were asked to provide feedback to the following questions:

- At your institution what are the new/exciting training programs/curricula in nano?
- What are the challenges you recognize in the training of future nanoengineers?
- What impact do you/your institution expect NINE to make?
- What three things do you hope to gain from this partnership? What one thing would you like to avoid?

In their presentations and in written responses, the presenters and other participants provided a broad range of answers to these questions. A few specific points were made by many of the responders:

1. Nanotechnology is an incredibly broad field but the NINE partner universities' programs cover a great many areas of it. Between the different universities a large number of courses are offered, some through distance learning. It should be possible to use this shared expertise to construct both basic and supplementary courses in nano engineering that can be used by all NINE partners. This could also include distance learning courses for NINE industry partners or for student interns working at either Sandia or an industry partner's facilities.
2. Curriculum development for nano engineering will be especially challenging because of the already crowded 4-year undergraduate curricula (+2 years for MS, + 5 years for Ph.D.) and the absolute requirement to preserve the technical depth needed for students to be successful. Several approaches were suggested including collaborative education efforts between physical sciences and engineering departments and finding opportunities to insert nanotechnology exposure opportunities into existing curricula (such as labs). The very multidisciplinary nature of nanotechnology that makes it opportunity-rich also

makes it very difficult to fit into a curriculum. NINE must avoid a "business as usual" approach to this effort.

3. NINE must emphasize broad and differentiating hands-on experiences for its students using a collaborative, team-based approach. Opportunities need to be focused on long term high value applications important to the nation and to American industry.
4. NINE must help students gain a system level understanding of the innovation process including how technological advances can be transformed into real world solutions. Industry guidance will be an important part of this.
5. All NINE partners want an opportunity to be part of, and have a voice in creating, a transformational solution to the need to create the next generation of leaders and innovators in the area of nanotechnology and nano engineering.
6. Partners want to avoid
    a. protracted IP negotiations and poorly thought out knowledge-sharing agreements,
    b. short term solutions to difficult problems of multidisciplinary curricula,
    c. losing the emphasis on intellectual depth in student's education

The first part of the Tuesday afternoon discussions were focused on getting feedback from the NINE partners on NINE goals, approaches, structure and elements. This was followed by the group dividing into three breakout sessions each discussing and providing feedback on one of the NINE elements. At the end of the day the sub-groups reported back to the full group and comments were captured from both the sub-group reports and the resulting larger group comments. These are summarized in the next section.

On Wednesday morning Regan Stinnett, Sandia's new program manager for NINE, presented an updated structure based on the original strawman structure but modified based on the groups comments on Tuesday. This presentation is on the NINE web site. The points captured in it are similar to those outlined in the next section.

After these discussions the three theme area leaders, Mary Crawford, Chris Apblett, and Alec Talin/Matt Blain provided brief summaries of the on-going NINE technical projects in the areas of Nanotechnologies for Energy, Nanosynthesis and Nanomanufacturing and Nanoelectronics and Quantum Information Processing. These are also on the NINE web site. At the conclusion of these presentations the workshop ended with a broad consensus that the NINE partners would continue to work together to make the NINE vision a reality.

Partner Observations and Recommendations:

Throughout the workshop and especially during the Tuesday afternoon discussion sessions, partner feedback and opinions on NINE challenges, goals and structure were captured and are provided below. This feedback has been organized around the three NINE Elements as discussed previously.

Enrich technical education

- Advantages of NINE for technical education:
  - The opportunity for students to work as part of large project teams with multiple universities, industry & Sandia; working on large problems at top facilities is unique and provides huge advantages of scale
  - Also good interactions between undergrads, grads, post-docs in the pipeline
- NINE can't directly interact with a significant number of the total engineering student population, so it must focus …
  - Teach the "Best and Brightest" to be tomorrow's tech leaders, emphasizing U.S. national priorities and participation by U.S. citizens
  - But also make NINE a socket anyone can plug into by providing different programs, some for low numbers of students with high level of interaction, some for high numbers with lower interaction
  - Include diversity too – we need leaders from all segments of the population
- Use distance education technology to involve all NINE partners
  - Weekly Nano Seminar series, bite-size Nanopedia concept
  - Virtual courses in nanotech science & engineering
  - Some material from university partners, some created specifically by and for NINE. Curriculum development is important and difficult.
- Issues include the difficulty of long distance involvement and supervision by faculty, the difficulty posed by current export control laws, and accommodating foreign national students.
- NINE activities must respect the academic calendar
- NINE must have separate programs for undergrads and graduates
- Undergrads
  - Could start summer after freshman year
  - Provide interesting hands-on work and tech exposure
  - Integrate nano-focused labs within existing courses
  - Pay undergraduates to work with grad students
- Graduate students
  - Work on large team projects with real deliverables, real world constraints, and faculty involvement
  - Learn from multiple mentors
  - Need stable, flexible student funding for 3-4 years
  - Need seamless connections with all players
- Addressing K-12 may be too much for NINE, but NINE can be a supporter of the effort
- Universities provide curriculum – NINE could sponsor student's access to university's video courses
- Faculty involvement will be problematic even with funding. Funding 2-3 students might be needed to get full faculty attention

Provide access to state-of-the-art capabilities

- Sandia facilities (CINT, MESA, AML, IMRL, CSRI, …) are unique in combination
- The power of NINE is integration
- Ability to build a prototype, real products are key
- Begin with Sandia facilities as the hub and hope to form a broader network later. University facilities are valuable too but harder to access broadly.

- Both university and industry personnel will benefit from access to Sandia facilities
- Access is not "equipment for hire"
- Ability to work together will naturally result in joint proposals and interdependence

Inspire translation of ideas to reality

- NINE's primary goal is to turn out people who will turn out the next big things in nanotechnology
- Students need exposure to real world concerns
- Broad exposure to concepts and skills needed for creating real world solutions is important and adds uniqueness to NINE. Students should take at least some courses.
- NINE needs to include both technology and business
- There might be a business package that would be a useful, non-thesis-related activity
- Do this work as part of a real project with a real world application and a team focus
- Teams should be assembled with consideration of students' choice of projects
- Mentors/liaisons should have lots of contact with teams to assure ideas have merit
- Goal is to provide an educational/technical problem for which students develop solutions while learning about project management, business, product design, IP etc.

Other issues and ideas discussed

- A fourth theme area, possibly focused on nano-bio, should be considered
- Check out SRC's programs for solutions to difficult issues like IP
- Must have open interactions - IP and other legal concerns make collaboration hard
- Cooperation maximizes ROI
- Solid state lighting is a good undergrad area
- Several partner universities have nano videos or courses that NINE could use
- NINE can help university nano programs reach critical mass
- Export control laws could make it very difficult to work with foreign nationals
- NINE should begin to work details like IP, proposal process definition, what we offer students, eligibility, Exec Board make-up, …

Summary

As an overall result of this workshop the group agreed to the following high level points:

- The combination of government labs, universities, and industry under DOE sponsorship to develop the next generation of nano-engineering innovators is a powerful and highly desirable combination
- The application focus of this effort should be on solutions to important national problems that will attract the nation's best and brightest students. Guidance from industry in identifying the most important problems and selecting the most effective approaches will be crucial to success.
- The three NINE elements proposed above, (1) enrich technical education, (2) provide access to state-of-the-art capabilities, and (3) inspire translation of ideas to reality, provide a good framework for exploring the optimum NINE structure.

At the concluding session of the workshop, all NINE partners present agreed that they could support the NINE goals, structure, and proposed path forward that we discussed and recorded.

Future meetings to define NINE IP policy, by-laws, as well as to review progress on technical projects and progress toward a proposal to make NINE a Discovery Science, Engineering and Innovation Institute were envisioned to take place in FY08.

To support ongoing collaboration, the NINE staff has created a password protected web page that only NINE partners can access. The web page provides a central storage and collaboration space for documents, information, and ideas. NINE partners are able to contribute their own content as well as comment on/contribute to other partners' content.

This workshop was an outstanding success, resulting in new working relationships, useful feedback on activities, and general agreement among NINE partners on our path forward.

Appendix A – Workshop Participants List

Participant List

NAME	ORGANIZATION	TITLE
Industry		
Mark Disko	Exxonmobil Upstream Research Company	Section Head for Advanced Sensing & Control Science
Greg Leeming	Intel Corporation	Program Manager for Focus Center Research Program
Ram Seetharam	Exxonmobil Upstream Research Company	Supervisor, Advanced Simulation and Reservoir Management Section, Reservoir Division
University		
Shenda Baker	Harvey Mudd College	Professor of Chemistry
Paul Braun	University of Illinois at Urbana-Champaign	Associate Professor of Materials Science and Engineering
Steve Brueck	University of New Mexico	Director and Distinguished Professor of Electrical & Computer Engineering
Joe Cecchi	University of New Mexico	Dean of School of Engineering & Professor of Chemical & Nuclear Engineering
Abhaya K. Datye	University of New Mexico	Director, Associate Chairperson, & Professor of Chemical & Nuclear Engineering
Eric Dufresne	Yale University	Assistant professor of Mechanical Engineering, Chemical Engineering and Physics.
David Duquette	Rensselaer Polytechnic Institute	Head, Professor of Materials and Science Engineering,
John Ekerdt	University of Texas at Austin	Endowed Chair and Professor of Chemical Engineering
Paul Fleury	Yale University	Dean of Engineering & Professor of Engineering and Applied Physics
JM Geremia	University of New Mexico	Assistant Professor: Physics & Astronomy Department
Robert Graham	Harvard University	Director of McKay Lab Administration & Faculty of School of Engineering and Applied Sciences
Jung Han	Yale University	Professor of Engineering
Saif Islam	University of California-Davis	Assistant Professor of Integrated Nanodevices and Systems Research Electrical and Computer Engineering
Kevin Jones	University of Florida	Professor & Chair, Materials Science and Engineering,
Brian Korgel	University of Texas at Austin	Associate Professor of Chemical Engineering
Kevin Malloy	University of New Mexico	Associate Dean of School of Engineering & Professor of Electrical & Computer Engineering
Christos Maravelias	University of Wisconsin-Madison	Assistant Professor of Chemical and Biological Engineering
Nicola Marzari	Massachusetts Institute of Technology	Associate Professor of Materials Science and Engineering
Martha Mcdonald	University of Florida	Faculty Staff, Materials Science & Engineering
Michael Niemier	Notre Dame University	Research Assistant Professor of Computer Science and Engineering
Paul Peercy	University of Wisconsin-Madison	Dean of College of Engineering
Fred Schubert	Rensselaer Polytechnic Institute	Professor of Physics & of Computer and Systems Engineering

Government		
Mark Allendorf	Sandia National Laboratories	Technical Staff, Microfluidics
Christopher Apblett	Sandia National Laboratories	Technical Staff, Ceramic Processing & Inorganic Materials
Matthew Blain	Sandia National Laboratories	Technical Staff, Photonic Microsystems Technology
Katherine Bogart	Sandia National Laboratories	Technical Staff, Advanced Materials Sciences
Tim Boyle	Sandia National Laboratories	Technical Staff, Ceramic Processing & Inorganic Materials
Jeff Brinker	Sandia National Laboratories	SNL Fellow, Self-Assembled Materials
Brent Burdick	Sandia National Laboratories	Technical Staff, Licensing & IP Management
Wendy Cieslak	Sandia National Laboratories	Senior Manager, Science Technology & Engineering Strategic Initiatives
Mary Crawford	Sandia National Laboratories	Technical Staff, Semiconductors Material & Device Sciences
Duane Dimos	Sandia National Laboratories	Director, Materials Science & Engineering
Anna Gorman	Sandia National Laboratories	Contractor, Ceramic Processing & Inorganic Materials
Anne Mary Grillet	Sandia National Laboratories	Technical Staff, Microscale Science & Tchnology
Jianyu Huang	Sandia National Laboratories	Limited Term, Center for Integrated Nanotechnology Science
Bob Hwang	Sandia National Laboratories	Senior Manager, Energy Sciences
Justine Johannes	Sandia National Laboratories	Senior Manager, Materials Synthesis & Processing
Rick Kemp	Sandia National Laboratories	Technical Staff, Ceramic Processing & Inorganic Materials
Kevin Leung	Sandia National Laboratories	Technical Staff, Surface & Interface Sciences
Jim Miller	Sandia National Laboratories	Technical Staff, Ceramic Processing & Inorganic Materials
Lori Parrott	Sandia National Laboratories	Manager, Strategic Future
Randall Schunk	Sandia National Laboratories	Technical Staff, Multiphase&Nanoscale Transport
Rene Sells	Sandia National Laboratories	Business Analyst, Partnerships Development
Paul Smith	Sandia National Laboratories	Technical Staff, Licensing & IP Management
Regan Stinnett	Sandia National Laboratories	Manager, PM: National Institute of Nano-Engineering
Brian Swartzentruber	Sandia National Laboratories	Technical Staff, Center for Integrated Nanotechnology Science
Alec Talin	Sandia National Laboratories	Technical Staff, Materials Physics
Steven Walsh	Sandia National Laboratories	Contractor, Materials Synthesis & Processing
Dominique Foley Wilson	Sandia National Laboratories	Contractor, Science Technology & Engineering Strategy & University Research
David Womble	Sandia National Laboratories	Senior Manager, Computer Science & Mathematics
Thomas Zipperian	Sandia National Laboratories	Senior Manager, MESA Microfabrication