



Society of  
Manufacturing  
Engineers

One SME Drive, P.O. Box 930  
Dearborn, MI 48121-0930



# Productive Nanosystems: Launching the Technology Roadmap

*Don't miss this important event!*

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important event!*

# Productive Nanosystems: Launching the Technology Roadmap

**October 9–10, 2007**

DoubleTree Hotel Crystal City–National Airport  
Arlington, Virginia USA

Organized by:



Society of  
Manufacturing  
Engineers



**FORESIGHT**  
NANOTECH INSTITUTE  
Advancing Beneficial Nanotechnology

**Battelle**  
The Business of Innovation

*Images courtesy  
of Nanorex*

# Productive Nanosystems: Launching the Technology Roadmap

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For 20 years, researchers have explored the amazing promise of atomically-precise manufacturing. Now, for the first time, the *Technology Roadmap for Productive Nanosystems* will show the way forward, and the payoffs along the road, to this ultimate technological revolution.

Over the last two years, under Battelle's leadership, and hosted by four U.S. National Laboratories, researchers from academia, government, and industry have met to chart paths toward advanced, atomically-precise manufacturing. The resulting roadmap reveals crucial challenges and unexpected opportunities in the next steps forward. Join us for two intensive days with leading experts as we explore the power of advanced "bottom-up" nanotechnologies.

## Why You Need to Be There

This unique event will address your questions, show how to fulfill the enormous promise of nanotechnology, and explore a wide range of applications:

- Super-efficient energy collection and storage
- Medical devices to detect and treat diseases at their earliest stages
- Next-generation computation
- Advanced sensors
- High-performance aerospace materials
- Intelligent materials and devices
- Many other technologies

## Who Should Attend?

Anyone interested in unlocking the potential of productive nanosystems should attend, including:

- Research and development
- Design and engineering
- Manufacturing management
- Strategic planning
- Public policy makers
- Technology transfer specialists
- New product and business development
- Economic development
- Educators
- Media

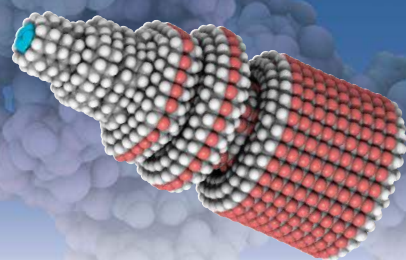
The full spectrum of organizations involved in nanotechnology will be represented at this event including corporations, research institutions, investors, economic development organizations, public policy groups, educators, and government agencies.

## Bonus: The Roadmap on CD

Following the event, SME will provide participants with access to presentations and technical papers from the event through a private website. In conjunction with Foresight Nanotech Institute and Battelle, **participants at the event will receive a CD-ROM containing the *Technology Roadmap for Productive Nanosystems*.**

## Acknowledgements

The organizers of the *Technology Roadmap for Productive Nanosystems* would like to thank the Roadmap Partners: Biotechnology Industry Organization, Electric Power Research Institute, NanoBusiness Alliance, Nano Science and Technology Institute, SEMI, and the Society of Manufacturing Engineers. Special thanks also goes to The Waitt Family Foundation and Sun Microsystems for financial support of the project.



## SPECIAL FEATURE: Feynman Prize Luncheon

The Feynman Prizes are given for advances in nanotechnology in two categories: experimental and theoretical. Established in 1993, the Feynman Prizes in nanotechnology are awarded to researchers whose recent work has most advanced the achievement of Feynman's goal for nanotechnology: the construction of atomically-precise products through the use of molecular machine systems. The 2007 winners will be announced and prizes will be presented during the luncheon.

## Program Committee

### Co-Chairs

- Jim Von Ehr, Founder, Zyvex Group
- Alex Kawczak, Vice President, Nanostructured Materials and BioProducts, Battelle

### Members

- K. Eric Drexler, Chief Technical Advisor, Nanorex
- Keith Firman, School of Biological Sciences, University of Portsmouth, UNITED KINGDOM
- Khiang Wee Lim, Executive Director, Institute of Materials Research and Engineering (IMRE), SINGAPORE
- Manish Mehta, Director, Collaborative Programs, National Center for Manufacturing Sciences
- Christine Peterson, Vice President, Foresight Nanotech Institute
- John Randall, Vice President, Zyvex Labs
- Christian Schafmeister, Department of Chemistry, Temple University
- Tihamer Toth-Fejel, Research Engineer, General Dynamics

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# Conference Agenda

## Tuesday, October 9

7:45 AM – 8:45 AM

### Check-in and Registration

8:45 AM – 9:00 AM



### Welcome and Opening Remarks

*Jim Von Ehr, Founder, Zyvex Group*

9:00 AM – 9:30 AM

### Toward Productive Nanosystems: Launching the Technology Roadmap

Productive molecular machine systems can enable economical, large-scale fabrication of products built with atomic precision.



However, a daunting implementation gap separates the nanostructures of today from the complex productive nanosystems needed. How can this gap be narrowed and eventually

closed? The development of tools to build these systems will require several intermediate stages, each building on the results of the previous stage, and each having its own commercial applications.

*Alex Kawczak, Vice President, Nanostructured Materials and BioProducts, Battelle*

9:30 AM – 10:00 AM

### The Building Blocks of Molecular Nanotechnology

A new technology for constructing large molecules with designed three-dimensional shapes and designed function has been



developed. The molecular building block methodology (syntheses of rigid molecular building blocks coupled through pairs of bonds), the automated synthesis of

macromolecules, the computer-aided design methodology, and some developing applications will be presented. An outline of how this technology could lead to the development of sophisticated molecular nanotechnology will be discussed.

*Christian Schafmeister, Department of Chemistry, Temple University*

10:00 AM – 10:30 AM

### Atomic Precision Patterned Atomic Layer Epitaxy: A Path to Atomically-Precise Manufacturing and Productive Nanosystems

A precursor to productive nanosystems is an atomically-precise manufacturing (APM)



process including atomically-precise depassivation lithography using a scanning tunneling microscope (STM) and atomic layer epitaxy (ALE) in a crystalline material system. This presentation

will describe efforts to develop atomic precision patterned ALE of Si, early commercial applications of this technology, approaches to dramatically improve the throughput of the process, and plans to extend atomic precision patterned ALE to include other semiconductors, insulators, and metals.

*John Randall, Vice President, Zyvex Labs*

10:30 AM – 11:00 AM

### Break

11:00 AM – 11:30 AM

### Biological Molecular Motors for Bionanotechnology

A few well-known molecular motors will be



described, their potential uses within nano devices will be illustrated, and work with an unusual molecular motor that provides a link between the biological world and the silicon world—acting as a

molecular dynamo—will be presented.

Potential application in areas as diverse as biosensing, drug delivery, responsive materials, and single molecule drug screening will be discussed.

*Keith Firman, School of Biological Sciences, University of Portsmouth, UNITED KINGDOM*

11:30 AM – 12:00 PM

### Atomistic Modeling of NanoScale Systems

Molecular dynamics simulations of protein structures for several microseconds of simulated time can be performed in matters



of weeks on next generation massively parallel computers. Inorganic clusters, such as those used in supported metal catalysts, will be supported by prediction of the geometrical

arrangement of the atoms or the optical absorption probability. Recent results in both areas obtained using large scale parallelism, and limitations which still exist in the ability to predict atomic scale properties, will be discussed.

*James W. Davenport, Director, Computational Science Center, Brookhaven National Laboratory*

12:00 PM – 12:30 PM

### KEYNOTE: Mapping Roads to Advanced Nanotechnologies

The Roadmap project has surveyed capabilities and prospects for the design and



fabrication of atomically-precise functional nanosystems. Progress can be quantified by performance metrics and charted in terms of successive generations of enabling technologies.

Increasing complexity will demand an increasing focus on system-level design and development.

*K. Eric Drexler, Chief Technical Advisor, Nanorex*

12:30 PM – 2:00 PM

### Feynman Prize Luncheon

2:00 PM – 2:30 PM

### Engineering Atomically-Precise Devices to Transform Molecular Structures

Computational design methods for proteins with novel ligand-binding sites and enzyme activities have been



developed and experimentally validated. Starting with a protein of known structure, the set of mutations necessary to alter or introduce ligand-binding or enzyme activity in that

structure are predicted. These designs can be produced by oligonucleotide-directed mutagenesis and heterologous protein expression. Biosensors for a wide variety of ligands, including TNT, nerve agent surrogates, and metabolites have been constructed.

*Homme Hellinga, Department of Biochemistry, Duke University*

2:30 PM – 3:00 PM

### New Synthetic Strategies to Build Protein Based Nanomaterials

The small size of new device components make it difficult to position them into



functional assemblies using existing patterning techniques. As one solution, the protein shells of two viruses have been converted into scaffolds that can position nanoscale objects with excellent spatial

resolution. This has been used to synthesize arrays of fluorescent molecules as well as using core/shell materials for applications in diagnostic imaging. These and other applications of the new materials will be presented.

*Matthew B. Francis, Department of Chemistry, University of California, Berkeley*

**For complete description of all presentations, visit [www.sme.org/nanosystems](http://www.sme.org/nanosystems).**

3:00 PM – 3:30 PM

### DNA Nanotube-Enabled Alignment of Membrane Proteins for NMR Structure Determination

The construction of atomically-precise, micron-length nanostructures that enable structure determination of membrane proteins, which represent the majority of drug targets, will be presented. Detergent-resistant liquid crystals of 0.8- $\mu\text{m}$ -long DNA nanotubes that enable weak alignment of detergent-reconstituted  $\zeta$ - $\zeta$  transmembrane domain of the T-cell receptor have been generated. The use of DNA nanotube struts to self-assemble icosahedral cages that are 100 nanometers in diameter and future application as encapsulation devices and drug delivery vehicles will also be discussed. *William M. Shih, Harvard Medical School and Department of Cancer Biology, Dana-Farber Cancer Institute*



3:30 PM – 4:00 PM

Break

4:00 PM – 4:30 PM

### Multifunctional Carbon Nanotube-Based Systems: Linking Synthesis and Function

Translating the properties observed for individual nanostructures to macroscale composites has proven difficult. This presentation will address the roadmap from nanoscale synthesis to macroscale functionality, starting with fundamental understanding of nanotube and nanohorn synthesis gained through *in situ* time-resolved characterization of their growth. Effects of processing and assembly on the path toward functional macroscale systems will be illustrated with several examples.

*David B. Geohegan, Distinguished Research Staff Member, Oak Ridge National Laboratory*

4:30 PM – 5:30 PM

### PANEL DISCUSSION: Pathways

**MODERATOR:** *Jim Von Ehr, Founder, Zyvex Group*

Multiple technologies are competing—and cooperating—in the drive to achieve atomically-precise manufacturing. This panel will debate how these R&D pathways interact and converge and how each pathway will be accelerated by unique achievements and payoffs in fields ranging from medicine to new materials to computation.

#### PANELISTS:

- Christian E. Schafmeister, Department of Chemistry, Temple University
- John Randall, Vice President, Zyvex Labs
- K. Eric Drexler, Chief Technical Advisor, Nanorex
- Keith Firman, School of Biological Sciences, University of Portsmouth

## Wednesday, October 10

7:45 AM – 8:00 AM

Coffee and refreshments

8:00 AM – 8:30 AM

### Nanophase Materials: A Persistent Enabler

Nanophase materials have been credited with enabling functional property control for both natural and synthetic structures. The advent of nanoscopy tools has allowed the pursuit of productive nanosystems. This presentation will focus on recent examples of functional nanosystems related to polymer synthesis and applications in photonics, energy conversion, and renewable materials.

*Dennis W. Smith, Jr., Department of Chemistry, Clemson University*



8:30 AM – 9:00 AM

### Single-Atom Manipulation and the Chemistry of Mechanochemistry

Central to advanced molecular manufacturing is the expectation of single-atom control for

the fabrication of nanostructures and, eventually, productive nanosystems. Quantum chemical studies of candidate single-atom assembly structures are an important design tool, providing both a means to design optimization, and the ability to predict failure rates and defect structures associated with potentially reactive molecular species.

*Damian G. Allis, Research Fellow, ICPRFP; Senior Scientist, Nanorex; and Theorist in Residence, Syracuse University*



9:00 AM – 9:30 AM

### Biological and Nanoscale Systems

The need to understand and engineer systems on similar scales presents a mutually beneficial merging of bio- and nano-sciences.

This convergence can result in an unprecedented understanding of biological function and opportunities to apply biology's engineering principles. An example of this will be presented, highlighting how the physical characteristics of the cell can

be mimicked with nanomaterials to create novel analytical devices and to reveal details of natural cell function.

*Mitchel J. Doktycz, Research Staff, Oak Ridge National Laboratory*



9:30 AM – 10:00 AM

### Atomic-Scale Device Fabrication in Silicon

A complete fabrication strategy towards atomic-scale device fabrication in silicon using phosphorus as a dopant in combination with scanning probe lithography and high purity crystal growth will be demonstrated. This process has been used to fabricate conducting nanoscale wires with widths down to ~8 nm, tunnel junctions, single electron transistors, and arrays of

quantum dots in silicon. An overview of the devices made with this technology and some of the challenges to achieving atomically-precise devices will be presented.

*Michelle Simmons, School of Physics, University of New South Wales, AUSTRALIA*



10:00 AM – 10:30 AM

Break

10:30 AM – 11:00 AM

### Nanotechnology in Singapore: Towards Atomic-Scale Manufacturing

The Agency for Science, Technology and Research (A\*STAR) of Singapore has identified several strategic areas that include nanomagnetism, nano/micro fabrication, nanophotonics, and nanobiomimetics with applications in engineering sciences and human health. For example, at IMRE, activities in atomic scale

technology focus on atomic scale manipulation and miniature scanning probe-type devices.

*Khiang Wee Lim, Executive Director, Institute of Materials Research and Engineering (IMRE), SINGAPORE*



11:00 AM – 11:30 AM

### Information Technology: Toward the Atomic Scale

New lithographic processes, combined with increasingly sophisticated processes of natural pattern formation (templated and directed self-assembly), will enable us to learn to build

objects with complex structure defined down to the atomic scale. This will require judicious choice of building blocks, clever dynamical steering of the self-assembly process, and design of structures that are

tolerant of some defects. Although this is a long-term vision, sophisticated self-assembly processes are already beginning to enter high-volume semiconductor manufacturing. *Thomas Theis, Director, Physical Sciences, IBM Watson Research Center*





11:30 AM – 12:00 PM

**Feynman Prize Winner: Theory**

The 2007 winner will present the award-winning work in the area of theory.

Previous winners include:

- Erik Winfree and Paul Rothemund, California Institute of Technology
- Christian Joachim, Center Nationale de la Recherche Scientifique, FRANCE
- David Baker, University of Washington and Brian Kuhlman, University of North Carolina
- Don Brenner, North Carolina State University
- Mark Ratner, Northwestern University
- Uzi Landman, Georgia Tech
- Ralph Merkle, Zyvex and Stephen Walch, ELORET NASA Ames

12:00 PM – 12:30 PM

**Feynman Prize Winner: Experimental**

The 2007 winner will present the award-winning work in the area of experimental.

Previous winners include:

- Christian Schafmeister, University of Pittsburgh
- Homme Hellinga, Duke University
- Carlo Montemagno, University of California at Los Angeles
- Chad Mirkin, Northwestern University
- Charles Lieber, Harvard University
- Stan Williams and Philip Kuekes, HP Labs and James Heath, University of California at Los Angeles
- Phaedon Avouris, IBM
- Reza Ghadiri, Scripps Research Institute

12:30 PM – 1:45 PM

**Luncheon**

1:45 PM – 2:15 PM

**Low Cost, Atomically-Precise Manufacturing of Defense Systems: Progress and Applications**

Productive nanosystems based on molecular machines are the only known technological



approach that can satisfy the manufacturing objective of making large objects to atomic precision at a lower cost. Productive nanosystems will allow the manufacture of structural materials that approach their theoretical strength limits—about 100 times stronger than today's metals and plastics—enabling the DoD to substantially reduce energy consumption and environmental pollution.

*David R. Forrest, Engineer, Naval Surface Warfare Center and President, Institute for Molecular Manufacturing*

2:15 PM – 2:45 PM

**Molecular Design of Solid State Lighting for Energy Efficiency**

Solid-state lighting based on inorganic III-nitride light emitting diodes is already achieving market penetration in niche



segments. Examples from semiconductor technology and biology will be used to illustrate the importance of molecular scale precision for high efficiency solid-state lighting. The challenges, progress, and remaining roadblocks to a viable organic solid-state lighting technology will be discussed.

*Paul E. Burrows, Laboratory Fellow, Pacific Northwest National Laboratory*

2:45 PM – 3:15 PM

**A Comparison of Nanotechnology-Enabled Photovoltaic Materials and Devices with Near-Term Commercialization Potential**

Several photovoltaic technologies that are viable for near-term commercialization, within approximately five years, will be



compared and contrasted. Not all of these are nanotechnology-enabled technologies. The prospects of such technologies being deployed in wide-scale photovoltaic applications in the near term will be

examined. Several of these technologies are being developed through the Wright Center for Photovoltaics Innovation and Commercialization (PVIC), a program funded by the Ohio Third Frontier Program.

*Robert J. Davis, Director, Nanotech West Laboratory, The Ohio State University*

3:15 PM – 3:45 PM

**Break**

[www.sme.org/nanosystems](http://www.sme.org/nanosystems)

3:45 PM – 4:45 PM

**PANEL DISCUSSION: Applications**

*MODERATOR: Pearl Chin, President, Foresight Nanotech Institute*

Work toward productive nanosystems results in new commercial applications at virtually every step. The increasing ability to



control matter to atomic precision enables major leaps in power generation and storage, computation density and efficiency, high performance sensors, and materials for aerospace that outperform past

achievements by surprising factors. This panel will explore the possibilities from near-term and practical to longer-term and visionary.

**PANELISTS:**



Malcolm R. O'Neill, former CTO, Lockheed Martin; and Chairman, Board on Army S&T, The National Academies



Thomas Theis, Director, Physical Sciences, IBM Research



Papu Maniar, Advanced Materials and Nanotechnology Manager, Motorola



J. Storrs Hall, Research Fellow, Institute for Molecular Manufacturing

4:45 PM – 5:00 PM  
**Closing Remarks**

**LOCATION AND LODGING**

**DoubleTree Hotel  
Crystal City–National Airport**  
300 Army Navy Drive  
Arlington, VA 22202-2891 USA

**Room Reservations: Call the hotel directly at +1 (703) 416-4100** and mention SME and this event to receive the reduced room rate of **\$169/per night** (single and double). Rooms that are not reserved **by September 17, 2007**, will be released. After this date, room availability and SME's reduced rate cannot be guaranteed.

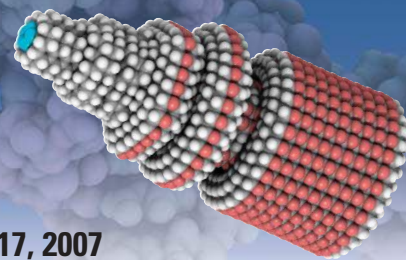
**Location/Hotel Amenities:** The Doubletree Hotel Crystal City is a full service, upscale contemporary hotel featuring spacious, well-appointed rooms and suites with a long list of amenities, including high-speed internet access, fitness room, indoor heated pool, and sight seeing tours. A popular destination with locals as well as visitors, the DoubleTree's Skydome Lounge is the area's only revolving rooftop lounge featuring excellent views of the Capital and the Potomac.

Visit [www.sme.org/nanosystems](http://www.sme.org/nanosystems) to make reservations online and for driving directions.

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DoubleTree Hotel Crystal City–National Airport • Arlington, Virginia USA



## REGISTRATION FORM – Early registration discount ends September 17, 2007

PRIORITY CODE: \_\_\_\_\_

*(located above mail address panel or at the bottom of email)*

### ATTENDEE INFORMATION *(one registration form per person)*

**PLEASE PRINT**  Mr.  Dr.  Prof.  Ms.  Mrs.

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Please do not use my e-mail for communication outside of SME.

#### Select your **ONE** primary job function *(if student select other)*.

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|---|---|
| 2 <input type="checkbox"/> Company Management/Corporate Executive | 5 <input type="checkbox"/> Quality Management         |
| 3 <input type="checkbox"/> Manufacturing Production               | 6 <input type="checkbox"/> Product Design/Development |
| 3A <input type="checkbox"/> Manufacturing/Operations Management   | 6A <input type="checkbox"/> Research & Development    |
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| 4D <input type="checkbox"/> Mechanical Engineer                   | 9D <input type="checkbox"/> Educator/Instructor       |
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|   | 10 <input type="checkbox"/> Other                     |

#### Select the number of employees at your organization.

- |   |   |
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| 0 <input type="checkbox"/> Less than 20 | 4 <input type="checkbox"/> 250-499        |
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| 3 <input type="checkbox"/> 100-249      | 7 <input type="checkbox"/> 2,500 and Over |

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|--|---|
| <b>MANUFACTURING</b>                                       | <b>NON-MANUFACTURING</b>                          |
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### REGISTRATION OPTIONS

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**CALL:** SME Customer Service at + 1 (800) 733-4763 or + 1 (313) 271-1500 ext. 4500, M–F, 8 AM–5 PM ET

**ONLINE:** [www.sme.org/nanosystems](http://www.sme.org/nanosystems)

### REGISTRATION FEES

|   | THRU<br>9/17/07 | AFTER<br>9/17/07 |
|---|-----------------|------------------|
| <input type="checkbox"/> <b>SME and Endorsing Partners Member Rate</b> (CF07REG17)<br>I am a member of: <input type="checkbox"/> SME <input type="checkbox"/> Foresight <input type="checkbox"/> Battelle <input type="checkbox"/> Endorsing Partner<br>Membership # _____ (required for member rate) | \$495           | \$545            |
| <input type="checkbox"/> <b>Nonmember Rate</b> (CF07REG17)  | \$695           | \$745            |
| <input type="checkbox"/> <b>New SME Membership</b> (optional)<br><b>Save \$75!</b> Purchase a new SME membership and get the SME member rate today.   | \$125           | \$125            |
| <b>AMOUNT DUE</b>   | \$ _____        | \$ _____         |

**\*Members of Endorsing Partners:** To obtain the membership rate please **phone, fax, or mail** your registration form. At this time, online registration is only available to SME members, nonmembers, and purchasers of a new SME membership.

### PAYMENT

Registrations will not be processed without complete payment information. Please make check or money order payable to SME in U.S. funds.

### PAYMENT METHOD

Check/Money Order  Discover  Visa  MasterCard  American Express

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**CCV:** On VISA/MasterCard/Discover, the 3-digit CCV number is printed in the signature area on the back of the card. For American Express, the 4-digit CID code is located on the front, in the upper right corner directly above the credit card number.

Attendance is limited and only preregistered, prepaid registrants will be guaranteed access to the conference.

**When registering less than two weeks prior to the program, please call + 1 (800) 733-4763 or + 1 (313) 271-1500 ext. 4500.** Upon receipt of your paid registration, you will be sent a registration confirmation.

**ON-SITE REGISTRANTS:** On-site registration is on a space-available basis. Payment is due on-site.

**CANCELLATIONS:** Cancellations will receive a full refund if made on or before September 28, 2007. Beginning September 29, 2007, cancellations will receive a 50% refund. You must obtain a cancellation number from our registrar to verify your cancellation. Confirmed registrants who do not notify SME of his/her cancellation are not eligible for a refund.

**METHOD OF PAYMENT:** Checks and money orders should be made payable to SME in U.S. funds. SME accepts VISA, MasterCard, Discover, and American Express.

**PROGRAM CHANGES:** SME has the right to amend this program as necessary. In the event of a cancellation, SME is not responsible for incidental costs incurred by registrants. We recommend purchasing refundable airline tickets.

**DISABLED PERSONS ACCOMMODATIONS:** SME is committed to providing reasonable accommodations to individuals with disabilities so they may fully participate. Please call SME Customer Service at + 1 (800) 733-4763 or + 1 (313) 271-1500 ext. 4500 at least two weeks prior to the conference to arrange special accommodations. Please call the hotel directly at +1 (703) 416-4100 to inquire about special parking.

