U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

U.S. DOE and DOD Manufacturing Innovation Multi-Topic Workshop

- Engineered Nanomaterials
- Advanced Sensing, Control and Platforms for Manufacturing (ASCPM)
- High Value Roll-to-Roll (R2R)
- Advanced Materials Manufacturing (AMM)
- High-Efficiency Modular Chemical Processes/Process Intensification (HEMCP/PI)
- Modern Fibers and Textiles

October 8 and 9, 2014
Fort Worth, TX

The DOE Office of Energy Efficiency and Renewable Energy (EERE)'s Advanced Manufacturing Office partners with industry, small business, universities, and other stakeholders to identify and invest in emerging technologies with the potential to create high-quality domestic manufacturing jobs and enhance the global competitiveness of the United States.

The U.S. Department of Defense (DoD) Manufacturing Technology (ManTech) Program develops technologies and processes for the affordable, timely production and sustainment of defense systems. The program impacts all phases of acquisition. It aids in achieving reduced acquisition and total ownership costs by developing, maturing, and transitioning key manufacturing technologies. Investments are focused on those that have the most benefit to the warfighter and include quick-hitting, rapid response projects to address immediate manufacturing needs.

This document was prepared for DOE/EERE's AMO by Energetics Incorporated, Columbia, MD.

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WORKSHOP OVERVIEW

The U.S. Department of Energy (DOE) and Department of Defense (DoD) held a Manufacturing Innovation Topics Workshop on October 8 and 9, 2014. Representatives from industry, academia, DOE national laboratories, and DoD centers gathered in Fort Worth TX to hear keynote addresses and participate in workshop breakout sessions. Discussion topics focused on challenges of manufacturing for clean energy manufacturing applications and considerations for possible new National Network for Manufacturing Innovation (NNMI) Institutes.

Manufacturing remains the essential core of the U.S. innovation infrastructure and is critical to economic growth and national defense. Experts point to a gap in the innovation continuum that exists between R&D activities and the deployment of technological innovations in the domestic production of goods. Concerns have been raised that this gap could have long-term negative consequences for the economy and the defense industrial base. As global competition to manufacture advanced products intensifies, the performance of the country's innovation ecosystems must improve. Industry, academia, and government partners need to leverage existing resources, collaborate, and co-invest to nurture manufacturing innovation and accelerate commercialization and defense productization.

The President of the United States launched the NNMI as a major, new initiative focused on strengthening the innovation, performance, competitiveness, and job-creating power of U.S. manufacturing. (See www.manufacturing.gov). This initiative is providing the required innovation ecosystem to help bridge the gap between basic research and product development/fielding. It provides shared assets to help companies, particularly small and medium enterprises, access cutting-edge capabilities and equipment and creates an unparalleled environment to educate and train the workforce for advanced manufacturing implementation. As part of the NNMI, the Federal government is establishing new NNMI Institutes to fill the gaps in the innovation infrastructure.

DOE and DoD both value input from industry and academia as part of the effort to select and scope technology focus areas for future NNMI Institutes. These Institutes are regionally centered Public Private Partnerships (PPP) that enable the scale-up of advanced manufacturing technologies and processes and encourage commercialization of existing science and technology.[1] Each Institute will be led by a not-for-profit organization and focuses on one technology area. DOE and DoD requested assistance in selecting a technology focus area for an NNMI Institute consistent with their respective missions, based upon evidence of national security requirement, economic benefit, technical opportunity, relevance to industry, business case for sustainability, and workforce challenge.

The Advanced Manufacturing Office (AMO) within DOE's Office of Energy Efficiency & Renewable Energy (EERE) partners with private and public stakeholders to improve U.S. competitiveness, save energy, create high-quality domestic manufacturing jobs and ensure global leadership in advanced manufacturing and clean energy technologies. AMO invests in cost-shared research, development and demonstration (RD&D) of innovative, next generation manufacturing processes and production technologies that will improve efficiency and reduce emissions, reduce industrial waste, and reduce the life-cycle energy consumption of manufactured products. The results of this investment include having manufacturing energy efficiency harnessed as a competitive advantage, and cutting-edge clean energy products competitively manufactured in the United States. AMO is particularly interested in the challenges associated with advanced manufacturing technology that might be overcome by pre-competitive collaborations conducted via a NNMI Clean Energy Manufacturing Innovation Institute.

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[1] NNMI Concept and Design, Executive Office of the President, January 2011

The DoD Manufacturing Technology (ManTech) Program in the Office of the Secretary of Defense (OSD) develops technologies and processes for the affordable, timely production and sustainment of defense systems. The program impacts all phases of acquisition. It aids in achieving reduced acquisition and total ownership costs by developing, maturing, and transitioning key manufacturing technologies. Investments are focused on those that have the most benefit to the warfighter and include quick-hitting, rapid response projects to address immediate manufacturing needs. ManTech focuses on the needs of our warfighters and weapon system programs by helping to find and implement affordable, low-risk solutions. ManTech provides the crucial link between technology invention and development and industrial applications; matures and validates emerging manufacturing technologies to support low-risk implementation in industry and DoD facilities, e.g., depots and shipyards; and addresses production issues from system development through transition to production and sustainment. The DoD Defense-Wide Manufacturing Science and Technology (DMS&T) program, part of the OSD Manufacturing and Industrial Base Policy (MIBP) office, partners with private and public stakeholders to improve U.S. competitiveness, save energy, create high-quality domestic manufacturing jobs, and ensure global leadership in advanced manufacturing and clean energy technologies.

At the workshop, participants identified mid-Technology Readiness Level (TRL) research and development (R&D) needs, market and supply chain challenges, and shared facility needs for advanced manufacturing. The workshop complemented two AMO Requests for Information (RFI): the first RFI, issued in the spring of 2014, solicited industrial and academic input on a broad range of cross-cutting technologies that could be benefit from investment in a NNMI Institute; the second RFI, issued in late summer of 2014, was more narrowly focused. In addition, there is a recently amended DoD/OSD ManTech RFI. AMO and ManTech sought to know more about the challenges associated with advanced manufacturing technology that potentially could be overcome by pre-competitive collaboration as part of a potential new NNMI Institute.

The workshop discussions provided AMO and ManTech managers with further information on both cross-cutting and specific manufacturing challenges as well as a basic rationale for an innovation institute, consistent with the missions of the DOE and DoD. Presentations given at the workshop are available at http://energy.gov/eere/amo/downloads/manufacturing-innovation-multi-topic-workshop. At the workshop, DOE led four breakout sessions and DoD led two, as shown below.

DOE

- Advanced Materials Manufacturing (AMM)
- Advanced Sensing, Control, and Platforms for Manufacturing (ASCPM)
- High-Efficiency Modular Chemical Processes (HEMCP)
- High Value Roll-to-Roll Manufacturing (R2R)

DoD

- Engineered Nanomaterials
- Modern Fiber and Textiles

Participants in each breakout session answered a different set of questions that were appropriate for the topic. Summaries of the six workshop breakout group discussions, along with the questions, are presented below. The Appendix includes an Agenda, a combined list of participants from all the breakout groups, and an acronym list.

BREAKOUT GROUP SUMMARIES

1. ENGINEERED NANOMATERIALS

Introduction

Nanotechnology research has shown great promise in applications ranging from electronics to pharmaceuticals and structures to membranes, but scale-up and commercialization has lagged behind this research. During the past decade, federal funding of nanotechnology research under the National Nanotechnology Initiative (NNI)[2] more than tripled annually from about $464 million to almost $1.5 billion as the total U.S. investment in the technology reached to over $20 billion. NNI characterized the 10-year period from 2001 to 2010 as the "first foundational phase" and focused on inter-disciplinary research at the nano-scale. This phase led to discoveries of new phenomena, properties and functions at the nano-scale, a library of components as building blocks for potential future applications, and improvement of existing products by incorporation of relatively simple nano-scale components and technologies. While this phase has created a substantial body of knowledge in nanotechnology, the number of products in the commercial marketplace that benefit from nanotechnology is still fairly limited.

More importantly to the needs of manufacturing, nano-engineered materials require consistent, repeatable processing, implementation, and characterization of nano-input materials. Current in-process measurement methods on the industrial scale cannot provide the necessary base for scale-up of production. This limitation and others confine nano-engineered materials and their implementation to batch-processing and limited scale. Applications for engineered nanomaterials typically emerge from small businesses with niche applications that have a higher tolerance for risk. Until the input materials and their incorporation into products can be reliably controlled through the scale-up process, the promise of nanotechnology may go unmet.

Large investments in basic research have driven innovation, but many challenges, particularly in the scale-up of manufacturing processes still hinder nanomaterials development at a production volume sufficient for commercialization. A national manufacturing institute focused on engineered nanomaterials would have a tremendous opportunity to complete the development cycle by addressing the scale-up and qualification/certification challenges of manufacturing nano-engineered materials and unlock the vast potential of this technology for both the commercial marketplace and the DoD.

Workshop participants answered focused discussion questions to provide feedback on the proposed NNMI Institute objectives; to identify cross-cutting and specific challenges; and to define the basic rationale and justification for an NNMI Institute focused on Engineered Nanomaterials.

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[2] NNI is a U.S. Government's inter-agency activity for coordinating R&D as well as enhancing communication and collaborative activities in nanoscale science, engineering, and technology/ (http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf)

Challenges to Wide-Scale Adoption

QUESTION 1: What are the specific challenges within the TRL/MRL 4-7 area that prevent or limit wider-scale adoption today of Engineered Nano Materials and can these risks/barriers be quantified – please be specific?

Table 1 summarizes participants' comments on the current roadblocks and limitations to the pervasive use of engineered nanomaterials in existing products.

Table 1. Summary of Participants' Comments Related to the Challenges of Wide-Scale Adoption and Use of Engineered Materials

Technical

- Difficulty maintaining 'nano' characteristics in bulk materials
- High cost of production and quality control
- Limited access to materials' data characteristics – sharing is limited because the information is proprietary
- Few methods available to identify products that need functionality of nanostructures
- Lack of adaptable or easily modifiable surface functionality. Source materials require "rework"
- Immature processes require precise control of transport properties
- Few mature choices available since many materials are not TRL/MRL 4 or higher
- Limited control of nanomaterials agglomeration
- Difficulty consolidating nano feedstock into bulk form
- No leveraging of integrated dissimilar nanomaterials to exploit hybrid nanomaterial synergies
- Little recycling of waste

Measurement, Testing, and Characterization

- Lack of standards and affordable methods of measurement
- Limited environmental, safety, and health/OSHA standards related to processing and handling
- Limited availability of industrial equipment for characterization, testing, processing of materials
- Limited life-cycle based sustainability performance data of nanomaterials/products
- Few accelerated life test protocols
- Lack of good materials characteristics definition
- Difficulty with stability/reliability prediction of lifetime degradation mechanisms

Production and Manufacturing

- Insufficient low-cost, top-down nano processing to rapid nano prototyping/scale-up
- Lack of pilot scale instrumentation/equipment
- Lack of repeatable materials processing and production methods to obtain consistent nano-materials
- Lack of platform technologies/mesoscale assembly structures for use in traditional manufacturing processes to move nanomaterials into functional objects
- Limited knowledge and awareness of nano-manufacturing processes
- Difficulty in handling/moving nanomaterials during processing
- Limited rapid prototyping, rapid metrology, and rapid QA/QT
- Lack of sufficient/clearly defined supply (tons) and supply chain of pre-competitive development of material systems – lab productions are not scalable to production volumes, thus no stable supplies
- Instability of "functional" nanomaterials during scale-up – very different problems for different materials

Other

- Limited dissemination of know-how to produce nanomaterials
- Limited technology push or end-user market pull
- Risk aversion to sharing information needed for product optimization based on their proprietary systems

Table 1. Summary of Participants' Comments Related to the Challenges of Wide-Scale Adoption and Use of Engineered Materials
• Few feedback loops to other, lower TRLs/MRLs nanomaterials • Limited availability of business cases for inclusion of nanomaterials • Lack of systematic techno-economic and process simulation and modeling capabilities • Focus is on incremental innovation in the United States by industry; abroad, foreign governments work together with industry to aggressively develop TRL 4 to 7 materials

Nano Technology Processes

QUESTION 2: What nano-technical process areas should the NNMI Institute pursue to create maximum economic impact in the United States?

Table 2 summarizes participants' comments on the types of nanomaterials processes that a potential NNMI Institute should focus on.

Table 2. Summary of Participants' Comments Related to Focus areas for the NNMI Institute

Process Methods

- Develop scalable directed assembly of multi-materials
- Focus on various scalable processes like cavitation and precipitation to manufacture high-value materials like metals, carbon nanotubes, and graphene for industry
- Develop a platform for rapid multi-scale prototyping and characterization of materials
- Identify methods to process multifunctional materials in 1D, 2D, and 3D
- Develop nanostructural bulk materials that can have significant impacts, such as structural materials and magnetic materials
- Develop processes to scale-up production of advanced electrical conductors
- Merge bottom-up (i.e., chemical self-assembly of nanostructures, often in solution) with top-down processing (i.e., manufacture of nanostructures by physically positioning molecules)
- Develop multi-scale processes that can be controlled to achieve both technical and economic goals
- Develop nanomaterials focused on monitoring structural healing
- Archive knowledge about nanomanufacturing processes so at-scale unit processes translate between products
- Advance concepts of scalable synthesis
- Identify common nanomanufacturing processes that can benefit from further development

Process Tools

- Improve purification and contamination control processes – from raw materials to finished product
- Improve metrology and characterization methods for manufacturing process control at high rates of production
- Improve the capabilities of following tool types:
  - Characterization
  - Process modeling and monitoring
  - Qualification/certification/quality analysis/validation
- Develop tool-sets necessary for scale-up, e.g., simulation software, pilot-scale factories, quality assurance
- Design equipment for addressing large-scale dispersion and mesoscale building block assembly of heterogeneous systems/building/data
  - Focus on the needs of end-uses

Other

- Focus on materials of value before selecting synthesis processes
- Identify protocols that will allow sharing of specific industry proprietary systems and reduce risk
- Identify more opportunities for OEM-Tier 1 supplier involvement
- Focus on key technologies that support pilot processes that are driven by customers input
- Focus on support for small business to drive innovation
- Define building blocks for nanomaterials and nanomanufacturing
- Identify and nurture within the U.S. methodologies/processes that are critical for national security; replace critical materials sourced from outside the U.S. with nanoengineered materials
- Initiate conversations about data:
  - Representation
  - Storage

Table 2. Summary of Participants' Comments Related to Focus areas for the NNMI Institute
– Analysis/Analytics – Feedback – Sharing

Economic Impact of Engineered Nano Technology Advancement

QUESTION 3: In what areas does the United States lead in nanotechnology processes/ products? For industry, what are the most interesting nanotech process and or product areas? Where is the market pull?

Table 3 presents participants' ideas for the areas that U.S. engineered nanomaterial companies have market leadership. Participants also identified areas where the markets/products are searching for nanomaterials integrations.

Table 3. Summary of Participants' Comments related to Market Leadership and Market Pull

Market Leadership

- High conductivity and ultra-conductive nanomaterials
- Advanced electrical conductors for improved efficiency
- Nanoelectronics using III-V and II-VI compounds/materials
- Heterogeneous materials
- Structural health monitoring
- Self-assembly nano-materials (R&D)
- Nanocoating material and processes for auto/defense/aerospace applications
- Nanomaterials for oil and gas exploration.
- Nanoparticle imaging agents and pharmaceuticals

Market Pull

- Nanomaterials for food spoilage prevention
- Functional coatings, catalysts, and conductive materials with nanomaterials
- Selecting fewer and smaller nanomaterials
- Higher selectivity and activity from a nanocatalysts
- Seamless integration of the nanomaterials supply chain from Tier 3 building block material suppliers to OEMs
- Fast feedback from OEMs on nanomaterials R&D
- Timely feedback on industry's nanomaterials needs
- Advanced nanomaterial conductors – greater capacity, functionality, secure and reliable supply
- Mesoscale assembly by long range interactions of biomolecular and inorganic materials
- Assembly and manufacturing of heterogeneous materials to produce mesoscale technologies
- Combine missions of the nanotech centers across the United States with a new additional charter for advanced manufacturing
- Bio-nano technology interest from pharma-industry for medical applications, e.g., virus, genome, diseases
- Biosafe nano materials for medical applications
- Nanomaterials for optics and energy harvesting applications

Potential/Opportunity for an Institute

QUESTION 4: What evidence is there that a NNMI Institute for Nanomaterials could 1) be self-sustaining (i.e., no need for federal sustainment funding) after 5-7 years, 2) generate at least $75M in cost share, and 3) work to assure the United States remains at the forefront of nanomanufacturing?

Table 4 lists participants' ideas on the potential payback from a possible Engineered Nanomaterals NNMI Institute.

Table 4. Summary of Participants' Comments Related to Engineered Nanomaterials and Corresponding NNMI Institute Potential

Aspects that Suggest Self-Sustaining Institute

- Industry partner commitment to contribute cash in years after government funding ends
- Industry to government cost share needs to be $2-3 to $1
- Ensure big industry interests are met by focusing on applied R&D
- Encourage and engage small businesses
- Attract customers and maintain the interest of targeted stakeholders
- Cultivate conversations with academia and others
- Build tools for mid-TRL needs – this will help establish NNMI Institute self-sustainability
- Assess where large industry is today

Cost Share

- Numerous applications of nanomaterials could generate the necessary cost share
- Nanostructures (NS) in thin films
- NS in matrices (meso-building blocks)
- NS integrated on chips
- Functional materials
- Electronic and optoelectronics such as displays, TVs, LEDs, IR LEDs, RF devices, magnets, catalysts, batteries
- Others
- Large TRL 1-3 investments/startups are already in place that could feed to a NNMI Institute when the R&D matures
- States may be interested in cofunding
- SEMATECH can be model
- Other NNMI Institute successes can be used as a model for creating cost shares
- Cross-cutting nature of nanomaterials will ensure interest and funding from NNMI Institute partners

Nanomanufacturing Leadership

- Establish an NNMI Institute to help anchor nanomaterials development in the United States
- Long-term commitment with a NNMI Institute signals to industry that the U.S. is serious about nanomaterials development
- Need the ability to leverage close proximity of the R&D with manufacturing facilities
- "First mover" advantage – establishing a NNMI Institute shows interest and commitment to the topic
- An nanomaterials NNMI Institute will feed manufacturing technology to other institutes
- Need to identify target technologies in growing markets and identify target mesoscale opportunities for target technologies
- Enable rapid innovation and move faster than international competitors
- Strong intellectual property (IP) regulations and enforcement
- File U.S. patents
- File in countries where manufacturing occurs

Table 4. Summary of Participants' Comments Related to Engineered Nanomaterials and Corresponding NNMI Institute Potential
• File where finished products are being imported
Consequences of No NNMI Institute
• Foreign R&D advances past the U.S. capability • U.S. industry uses nanomaterials in specific applications without leveraging entire nanomaterials braintrust

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2. ADVANCED SENSING, CONTROL AND PLATFORMS FOR MANUFACTURING (ASCPM)

Introduction

Advanced Sensing, Control and Platforms for Manufacturing (ASCPM), also known as “Smart Manufacturing,” is a network data-driven process that combines innovative automation, and advanced sensing and control. ASCPM integrates manufacturing intelligence in real-time across an entire production operation, while minimizing energy and material use. AMO is interested in supporting U.S. manufacturing competitiveness and identifying the R&D needed for the development of 1) affordable, advanced industrial-data collection sensors and management systems, 2) industrial-community modeling and simulation platforms, and 3) technologies that reduce energy and greenhouse gas emissions (GHG) enterprise-wide,

Within the manufacturing sector, energy intensive manufacturing industries account for nearly 75% of all the energy used (over 20% of national energy use) and offer one of the largest opportunities for potential energy reductions. These industries produce and process basic materials and chemicals that go into many end-use consumer and industrial products. Energy intensive industries include primary metals (e.g., steel, aluminum, metal-casting), chemicals/petrochemicals, oil and gas refining, bio-manufacturing (e.g., pulp and paper), and nonmetallic minerals (e.g., glass, cement).

Advanced Sensing, Control, and Platforms for Manufacturing (ASCPM) enables both the virtual and physical connection of diverse systems and increases the collection and analysis of massive amounts data from advanced sensors and high performance computing platforms corresponding to device, process, plant and enterprises operational levels. This data provides highly accurate manufacturing intelligence that can be used to optimize energy, material, and resource use, as well as enable the design of detailed business models. This data can also be applied across different energy intensive industries and multiple manufacturing applications.

In recent years, consumers and selected manufacturing industries have employed information technology (IT)-based platforms and sensors to individual stages of decision-making and production. This Advanced Sensing, Control, and Platforms for Manufacturing (ASCPM) approach could lead to greater energy, material and resource efficiencies at lower costs, while achieving higher productivity and quality. However, technical advances have been slow to migrate to the energy intensive industry areas due to the 1) differences among continuous, high-volume batch, and discrete manufacturing processing methods, 2) low capital asset turnover rates, 3) legacy infrastructure (e.g. many disparate IT and process systems installed over decades,) 4) inaccurate process control models, and 5) harsh production environments.

A concept paper and a white paper were developed as a basis for specific topic areas of interest to be included in a Request for Information (RFI) titled Specific Clean Energy Manufacturing Focus Areas Suitable for a Manufacturing Innovation Institute, DE-FOA-0001158, released on August 29, 2014. However, further the public and private sector input was still needed to identify the critical ASCPM issues that might benefit from the support of an organized manufacturing innovation institute, as well as to assess the potential for an institute supporting domestically competitive clean energy manufacturing. The purpose of the ASCPM breakout session was to identify and prioritize ASCPM related challenges and synergistic opportunities related to the DOE CEMI.

The ASCPM breakout session focused on four key areas:

- Breakout Topic 1: ASCPM Technology Needs, Barriers, and Challenges
- Breakout Topic 2: Metrics for ASCPM
- Breakout Topic 3: ASCPM R&D Needs
- Breakout Topic 4: An Ideal ASCPM Institute

Focused discussion questions were prepared in advance. Individual participant's views and responses were captured using a compression planning and brainstorming process which draws on small groups to identify and/or analyze information in a compressed time period using the focus questions and story boards for a real-time capture of ideas.

ASCPM Technology Needs, Barriers, & Challenges

Focus Question 1: What are the ASCPM technology needs and technical challenges/barriers?

Table 1 summarizes participants' opinions on Focus question 1.

Table 1. Summary of Participants' Comments Related to Technology Needs, Barriers, Challenge for ASCPM

Data Algorithms

- Develop algorithms. Current manufacturing simulation software does not run well on high performance computing (HPCs)
- Develop distributed algorithms to run across manufacturing computing assets
- Develop feedback control algorithms that linearly couple distributed sensor data with a multi-unit operation processes and with distributed sensors and multiple feedstocks/products
- Develop data analysis algorithms that can create actionable knowledge at or near real-time from high volumes of complex data
- Turn information (big data) into knowledge that can be used to make real-time decisions, e.g., for health management
- Develop algorithm to enable zero defects and "first time right" for custom manufacturing (e.g., the algorithm model needs to predict, not just detect)
- Provide visual analytics for operators and others with the "right information" that they can act on

Sensors

- Develop self-powered remote sensors
- Develop efficient energy-harvesting materials
- Develop wireless sensor data with data sampling rates >10 kHz and costs < $50
- Establish property standards for sensor measurement in multiphase flow
- Co-develop solutions to problems and suitable metrology for control lags because manufacturing processes details strongly influence metrology instrumentation design and currently future process details are uncertain. Develop better, non-intrusive sensors for extreme conditions such as high/low temperatures and pressures
- Develop sensors that can survive the manufacturing process, but also be integrated into products and queried during the product's life cycle
- Develop sensors/packages resistant to harsh environments
- Develop open sensor platforms that can be used to sense different (needed) operating conditions and provide the requested data
- Develop sensors that meet a wide range of process parameters
- Develop smart sensors that are increasingly passive, plug-and-play, collect data, process data, and send information out
- Develop smart controllers that adapt as needed to different error recovery situations, handle more data, and revise control algorithms
- Develop sensors that cost-effectively bond to materials for harsh environment operation

Model

- Develop advanced energy consumption inference engine for automated production systems
- Orchestrate real-time data models analytics actionable in a customized and progressive manner on scaled IT and modeling infrastructure
- Develop HPC for real-time simulation and optimization of the right data verses big data
- Identify specifics corresponding to the environment: where sensors will be placed, how they will be powered, and the process to ensure that the sensors provide useful information
- Develop accurate and robust mathematical models and efficient real-time algorithm that will take advantage of the sensor data

Table 1. Summary of Participants' Comments Related to Technology Needs, Barriers, Challenge for ASCPM

- Develop distributed control technology that can exploit opportunities in massive sensing due to cheap sensor technology
- Identify "critical" data that can be collected at or near real time; this data can be used to predict the current and future "health" status, or vital signs, of the manufacturing line or process
- Provide more modular and scalable control methodology, which is highly flexible
- Develop better interoperability and connectivity for hybrid control environments
- Develop controls on a chip driven from models and simulations
- Develop sensing update models that turn issue commands into control command updates
- Develop networks/platforms that are self-aware and can organize "plug-and-play"
- Develop smart centralized control rooms for distributed systems optimization, prediction, and random access memory (RAM) security
- Develop models with improved accuracy and representation of the real world
- Develop generic data driver methodologies that need minimal customization
- Create models sophisticated enough to be useful – but simple enough for process operators to use
- Develop models that enable easy updates of manufacturing processes

Standards

- Standardize the communication protocol for sensor control and other advanced manufacturing systems
- Increase the number of standards for manufacturing equipment
- Establish interoperability and connectivity among a company's different manufacturing sites
- Establish broad/multi-collaborative platforms that align efforts and help define standards and direction
- Identify standards and calibration for new techniques and materials to enable scale-up for multiple technologies
- Identify interoperable software tools to simplify/eliminate the need for expensive middleware development
- Design tools that are accessible to users of all levels
- Connect disparate data points into a coherent whole

Focus Question 2: What are the challenges to implementation and deployment of ASCPM?

Table 2 summarizes participants' comments on Focus Question 2.

Table 2. Summary of Participants' Comments Related to Implementation and Deployment of ASCPM

Industry Base

- Identify the right partners to develop and implement the NNMI Institute

Tech Transfer

- Proof of concept ideas exist but funding is limited
- Identify ways industry can work with university scientists with similar research interests. They can learn from each other because they have different perspectives on the same research area. By working together, university researchers and industry may be able to develop a new "capstone" for a technology.

Skills

- Implement activities to address lack of skills, and data management; and cyber security challenges
- Promote innovative STEM (science, technology, engineering, and mathematics) education/engagement to prepare an innovative STEM workforce
- Develop a STEM workforce that is skilled in integrating physics, big data, economics, and analytics
- Develop cross-disciplinary education that integrates big data/statistics, sensors, manufacturing processes, and IT

Company Behavior

- Improve data sharing throughout the supply chain; reduce IP constraints between companies and suppliers
- Develop characterization tools to deal with proprietary data formats or lack of access to all data
- Analyze and address labor/management relations (e.g., tension between plant floor workers and facility management) to better enable technology implementation

Install Cost

- Use sensors so manufacturers can benefit from access to high-speed computing and data storage
- Develop classes or identify commonalities to deal with high variability or range of processes
- Customized software that integrates end-to-end sensing and control, is less expensive and less resource intensive
- Reduce worker training by improving the ease-of-use for manufacturing automation equipment
- Develop algorithms that are less time-consuming and less complicated to be used by operators
- Implement data collection (i.e., wireless sensor network) with minimal-disruption deployment approaches

ROI & Business Model

- Monetize benefits to facilitate decisions
- Quantify implementation costs (including IT infrastructure costs) and tangible monetary benefits in order to analyze cost-effectiveness
- Build a business case and educate decision makers
- Quantify return on investment (ROI) – the factors that influence ROI
- Recognize that market drivers are complex; achieving security is difficult
- Apply ASCPM knowledge to maintenance
- Migrate information from the current system to ASCPM
- Clarify the customization requirements for the ASCPM technologies needed for different industries; determine the benefits of this customization
- Engage a large number of participants successfully; educate decision makers about rewards verses financial risks
- Assess the impact and disruption on the existing manufacturing line resulting from incorporating sensors into the manufacturing line

Table 2. Summary of Participants' Comments Related to Implementation and Deployment of ASCPM
• Address organization inertia (e.g., resistance to change working systems with large sunk costs) and concerns regarding safety (e.g., if direct human intervention is removed) • Identify sensor reliability and design issues • Address the disconnect between the shop floor operation and system level management • Improve the visibility of cost reduction benefits • Consider the potential impact from changes to energy/carbon regulations • Improve the understanding of the value of integration across a wide range of manufacturing sectors

Metrics for ASCPM

Focus Question 3: What are the best parameters for measuring operational benefits of ASCPM?

Table 3 summarizes participants' comments on Focus Question 3.

Table 3. Summary of Participants' Comments Related to Metrics for ASCPM

For Products

- Use existing energy intensity measures
- Quantify the amount of energy consumed per part and compare it to the base process consumption ratio
- Predict the lifecycle energy produced to further energy consumed ratio
- Integrate indicators showing factory efficiency and supply chain operations
  - Existing: factory throughput ("turns") energy consumed per part
  - New: factory throughput ("factory turns") times estimated lifetime energy produced per part
- Use chemical composition specific to on-spec product for chemicals and fuels
- Use dollars per unit product or amount of CO_2 per unit product
- Reduce percentage of scrap
- Detect defects at the earliest step in manufacturing process
- Realize unit cost is the bottom line measurement

For Factory

- Identify a ROI that is workable. Consider metrics like a 20-40% reduction in energy usage, increased energy efficiency, and reduction in evening shutdowns
- Increase the "buy-to-fly" ratio by using advanced manufacturing and promoting efficient material usage
- Identify the next generation end-to-end supply chain
  - Demand dynamic (i.e., inability to react to demand)
  - Market accelerator
  - Sustainable rapid-value add
  - Productivity
  - Energy use leading to increased productivity sustained across the supply chain
- Address different levels of technology capability and readiness
- Identify the total value of energy consumed for cost of operations
- Identify variability/variation of process/operation
  - Coefficient of variation (CV) standard deviation/average value
  - Probability to deliver x products in T time units, etc.
- Emphasize long term measures (e.g., number of failures)
- Quality based competitiveness enabled by advanced sensors and control
- Conduct risk and failure analysis; include meantime to failures (MTF) and operations cycle improvement
- Efficiency: outage/cost productivity in 10 years long run future not only present day
- Percentage of uptime on the production line
- Overall equipment effectiveness
- Cycle and throughput
- Customer responsiveness
- Worker safety
- Product quality
- Reduce energy
- Increase productivity
- Achieve new goals
- Carbon footprint of manufacturing facilities

Table 3. Summary of Participants' Comments Related to Metrics for ASCPM

- Actual throughput vs. maximum possible
- Identify half-life of sensor

Enterprise Integration

- ASCPM performance characteristics:
  - Security (including wireless systems)
  - Compatibility, adaptability, and connectivity
  - Ease of use/implementation "foolproofness"
  - Scalability, modularity, and flexibility
  - Relevance and effectiveness
  - Visibility
  - Transparency of advanced controls
  - Data throughput
  - Optimization
  - Operational performance parameters (e.g., temperature, pressure, gas, vibration)
  - ROI (e.g., cost over the lifetime should be less than cost savings/lifetime)
  - Standardization – less inventory and training, easier purchasing and maintenance
- Manufacturing-oriented performance characteristics such as:
  - Time to market/product/cycle time
  - Production rate and overall yield rate
  - Overall unit manufacturing cost versus purchase cost
  - Operational performance metrics with defined reasons
  - Increase agility (i.e., the ability of handling changes and the ability to react effectively to changes in any inputs/conditions)
  - Identify profitability and competitive advantage
  - Safety
- End-to-end/local benefit:
  - Access level
  - Demonstration and capacity
  - Risk mitigation
  - Trust and security
- Technology development and deployment:
  - Number of industry partners participating (including OEMS, Tier 1, and Tier 2)
  - Address interoperability and compatibility; bring together representatives across the supply chain and focus more on "development" than "research"
  - Technology transfer should be more than one plant or industry and have impacts in the United States (software or hardware availability for critical and non-critical systems)
  - Ensure first deployments work well the first time - no failures; must not be worse than the existing process for the initial application (e.g., fail during use in the field)
  - Develop ways to meet customer demand and satisfaction
  - Address organization barriers (showcase an early result that demonstrates a significant competitive advantage from implementation and integration)

ASCPM R&D Needs

Focus Question 4: What are the hardware, modeling & simulation platform R&D needs for ASCPM? Areas may be in Standardized IT platforms, High performance computing solutions (e.g., modeling), Optimized co-design of process and sensing/control strategy.

Table 4 summarizes participants' comments on Focus Question 4.

Table 4. Summary of Participants' Comments Related to Hardware, Modeling & Simulation Platform R&D Needs for ASCPM

Hardware

- Develop
  - Sensor form factors
  - Interchangeable
  - Reliable and maintainable
  - Reconfigurable
  - Repeatable
  - R&D platform to develop new multifunctional sensor arrays, if needed
  - Durable non-RF sensors for extreme environments
  - High frequency data acquisition
  - Multi-sensor "dynamic" fusion
  - Appropriate ASCPM technology terminology
- Define equipment models
- Capture information from array of noisy and transient data (physics and data)

Software

- Provide an ability to trace the product
- Identify and develop open platform software and hardware
- Develop manufacturing, device control (translator universe), and industrial control digital control system (DCS)
- Develop software platform: key features include:
  - Share data and library
  - Model and analytics data management
  - Data integration
  - Interoperability
  - Associated standards
  - Network-capable
  - Orchestration
  - IT process
- Provide control and obtain information back from OEM software
- Develop open interface and communication protocols
- Develop an open platform to transfer data between enterprises across industry
- Harness information from noisy and dynamic data to "predict" faults, not just detect faults
- Sensor technology integration is often competitive (proprietary) based on previous experience it is not likely to be shared at an operations level

In General

- Detect early stage defects
- Measure operational benefits in terms of:
  - Productivity
  - Quality
  - Tractability

Table 4. Summary of Participants' Comments Related to Hardware, Modeling & Simulation Platform R&D Needs for ASCPM

  - Operating cost
  - Maintainability
  - Multi-product impacts
  - Product reliability affects the product
- Develop the ability to process highly transient and noisy acoustic data for health, safety and quality assurance
- Identify process for inserting ASCPM technology into the plant environment
- Improve flexibility in existing systems because every implementation is different

An Ideal ASCPM Institute

Focus Question 5: What is an Ideal ASCPM Institute under a Public Private Partnership (PPP) framework?

Table 5 summarizes participants' comments on Focus Question 5.

Table 5. Summary of Participants' Comments Related to an Ideal ASCPM Institute

Identity

- Form the institute around pre-competitive open, early TRL R&D or complimentary non-competitive TRL 4-7 activities
- Focus on solving one or two specific issues of importance
- Address issues in extreme environments and custom manufacturing
- Focus on two to three industries first and expand later
- Establish a consortia with mutual benefits and facilitate mutual exchange of information
- Develop methods to adapt sensors, with mode-based control simulation and optimization into industry and their manufacturing environment; precompetitive technology where results can be produced rapidly; separate projects where industry can create and protect IP using their own funding
- Develop industrial consortium with tiered membership: university, industry, not for profit
- Focus on end to end supply chain
- Allow effective technology transfer and retain IP

Role

- Prioritize industry needs
- Assist with technology and knowledge transfer
- Perform IP management
- Identify gaps/needs, and manage R&D and technology evaluation
- Provide facilities
- Provide access to industry
- Develop/define metrics, including institute success metrics
- Provide open tests and demonstrations
- Allow access to demonstrations
- Develop system of systems security
- Address a grand challenge and generate innovative technologies that provide a competitive edge to participating industrial members
- Drive standardization
- Provide rapid prototyping facilities
- Develop models that facilitate technology transfer (e.g., ROI)
- Give priority to cross-industry challenges
- Develop standards and identify common themes for R&D
- Facilitate different levels of R&D with hardware demonstration test beds
- Make results available to members
- Develop educational and workforce training materials
- Educate workforce for use and development of sensor and controls
- Establish sensor manufacturing development facility for the next generation of advanced smart sensors
- Develop an export control policy to ensure that the institute benefits U.S. manufacturing businesses
- Manage industry-directed technical programs, with a "manufacturing scale" manufacturing design facility that will develop the ecosystem and provide solutions to pre-competitive R&D
- Address competitive and common challenges while providing a friendly and flexible IP model
- Develop roadmaps, standards, models, metrology, testing

Table 5. Summary of Participants' Comments Related to an Ideal ASCPM Institute
• Develop the appropriate institute structure (e.g., consider a practice school model which sends student/faculty teams to member companies to solve their hardest problems; however, in this case, use faculty as the teams and bring the problems back to the institute to work on) • Demonstrate the entire integrated system • Serve as the facilitator for a supply chain network (i.e., architect) • Identify a testbed for industry applications

Focus Question 6: What is an Ideal ASCPM PPP framework?

Table 6 summarizes participants' comments on Focus Question 6.

Table 6. Summary of Participants' Comments Related to an Ideal ASCPM PPP Framework
User Interface Speed
• Focus on ease of use of model and simulation • Simplify R&D platform so that it is less complex and more user friendly for the industrial manufacturing engineer (does not need Ph.D.) • Develop intelligent platform that combines information from physics and data for real time control of processes and manufacturing lines
Modeling

• Develop open modeling and simulation tools that address industry's requirements; develop industry-led programs that demonstrate value
• Let industry drive the development to truly address industry challenges under the energy umbrella
  – Develop a balance view of long term vs. short term needs, successes, and failures criteria
• Identify facilities within institute membership to validate the technology
  – Test bed for advanced sensors, materials and device models both for manufacturing reliability and testing
• Work directly with the computer science community to bring in machine learning techniques
• Develop models that may need to be open sourced and modular so an effective architecture is necessary for deployment
• Develop extensible user tools
• Develop standard modules
• Identify critical parameters and data modules that are necessary and sufficient
• Develop end-to-end systems dynamics modeling to highlight bottlenecks before setting up factories, then refine based on experience to enable real-time factory throughput management with the goal of:
  – More parts per unit energy (existing)
  – More parts times lifetime produced energy per unit of time (new)
• Identify effective integration of different types of process models (e.g., continuous, discrete event) into plant data facility / enterprise-level decision-making model in real time
• Develop data driven modeling and variable selection that requires less customization
• Develop modeling platform with data (milliseconds) vs. alert (second) vs. decision (several second) time-scales
• Develop robust model to predict impending failures through field tests; they must be workable and understandable in a reasonable timeframe
• Develop real plant data for simulation verification, including properties for varying feel, steady state, and not-steady state operation:
  – Develop modeling and simulation platform such as hybrid hardware, software real-time simulation, and modeling that links input models with output and the controller
• Link, filter and aggregate sensor data to fit with model parameters
• Identify the right balance between accuracy and computation time
• Aggregate simulation with sensor data
• Identify standardized distributed sensing and control platform that supports simulation and demonstration (e.g., NREL Voltron)

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3. HIGH VALUE ROLL-TO-ROLL (R2R)

Introduction

High value roll-to-roll manufacturing (R2R) is used to support a wide range of competitive products in volume applications across many clean energy market sectors. The R2R technology platform is considered to be high throughput and high value-added for two-dimensional (2D) process methods that involve deposition of material(s) over large areas and onto moving webs or carriers or other continuous substrates.

The current challenge for R2R technology is the development of energy efficient, environmentally friendly, low cost R2R equipment, and process and production capabilities to manufacture high quality clean energy products for energy saving applications. Both DOE and DoD have an interest in high-value R2R manufacturing. The U.S. Air Force (USAF) is currently involved in obtaining more information from industry regarding 1) data on market demand for flexible hybrid electronics (FHE), 2) the size and composition of the industrial sectors affected by FHE technologies, 3) any evidence that can support a sustainable FHE industry base in the United States, and 4) what steps might be taken to ensure that an independent institute and a physical center would evolve after 5-years of initial funding[3].

AMO conducted a series of R2R inter-agency technical team meetings from February through June 2014. Participants included representatives from several DOE technology offices, DoD/OSD ManTech, U.S. Army (ARL), USAF (USAFRL), and the National Institute of Standards and Technology (NIST). This team shared information on the current state-of-the-art technologies and processes used in R2R manufacturing, reviewed current investments and interests by various agencies in technologies applicable to R2R manufacturing, and made suggestions for topics to be considered by a R2R Institute. DOE convened an internal High Value Roll-to-Roll (R2R) Manufacturing Technology Needs Workshop in April, 2014 to identify and prioritize R2R manufacturing-related challenges and synergistic opportunities related to the DOE Clean Energy Manufacturing Initiative (CEMI). Working papers were developed as a basis for specific topics areas of interest included in a Request for Information (RFI) titled Specific Clean Energy Manufacturing Focus Areas Suitable for a Manufacturing Innovation Institute, DE-FOA-0001158, released on August 29, 2014.[4]

However, further input was still needed from the public, the private sector, and other stakeholders. The breakout group at this meeting 1) identified critical advanced R2R manufacturing technology areas that might benefit from investments in a NNMI Institute, and 2) exchanged views on the long-term impact sustained by the industrial sector as it moves to support highly competitive domestic clean energy manufacturing, and address conventional manufacturing-related challenges, and opportunities.

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[3] DoD, Request for Information (RFI), #RFI-RQKM-2014-0022, 22 May 2014

[4] Department of Energy, Request for Information, "Specific Clean Energy Manufacturing Focus Areas Suitable for a Manufacturing Innovation Institute, DE-FOA-0001158, August 29, 2014. https://eere-exchange.energy.gov/#FoaIdd682ac7b-02d0-4c10-a424-7c00da3775a4

The R2R breakout session focused on four key areas:

- R2R Technology Needs, Manufacturing Challenges, and Investments
- R2R Process Deficiencies and Metrological Needs
- R2R Quality Systems and Synergy, and
- DOE Focus and Appropriate Mechanism for High Value R2R Manufacturing.

Four focused discussion questions were prepared in advance. Individual participant's views and responses were captured using a compression planning and brainstorming process which draws on small groups to identify and/or analyze information in a compressed time period using the focus questions and story boards for a real-time capture of ideas.

R2R Technology Needs, Manufacturing Challenges, and Investments

FOCUS QUESTION 1*:* What are the technology areas and industrial needs best supported by R2R manufacturing; what are the R2R technology needs and the manufacturing challenges to be solved by an institute (relative to production volume in any respective business sector, impact on public investment, attractiveness to private investment to commercialize, availability in a reasonable time frame, specific technology areas using R2R, geographical location, workforce availability, financing, rate of production, government/commercial equities, national security, incentives to incorporate R2R into existing manufacturing); and what rationale exists for the additionality of DOE investment as a proper role of government for a specific activity that would be best supported relative to private sector investments or is the private sector sufficient?

Table 1 summarizes participants' comments on a number of technology needs, manufacturing challenges and investment areas related to R2R manufacturing.

Table 1. Summary of Participants' Comments Related to Technology Needs, Manufacturing Challenges, and Investments for High-Value R2R Manufacturing

Technology Areas and Needs

- Focus on the areas of energy creation, storage, and management
- Investigate advanced capacitors for power electronics and energy challenges as well as polymeric high temperature materials (150-180 degree C) compatible with these products
- Look at hybridizing flexible photovoltaic (PV) thin-films with other energy related technologies such as those enabled with transparent conductive oxide (TCO) printing technologies
- Adapt primarily sheet-based engineered catalyst structures on thin film membranes to R2R processes for the application of energy storage
- Consider large areas and/or high volume distributed electronic systems not addressed by batch processing.
- Investigate low cost large area processing, low cost feedstock, low thermal budget (i.e., lower total amount of thermal energy transferred to a substrate during a given elevated temperature operation[5]), and printing technology
- Look at building integrated photovoltaic (BIPV) products impacting solar grid parity[6]
- Invest in technology areas related to coatings and membranes for use in electrochemical process tools and devices, resulting in high value R2R processes that are faster, cheaper, less energy intense
- Adapt and optimize sheet-based engineered catalyst structures on thin film membranes to R2R processes for the application of energy storage to reduce process energy intensity requirements
- Address engineering solutions to web handling of brittle layers, interconnects, and other substrates

Industrial and Manufacturing Needs and Challenges

- Analyze current-technology sheet-based processes at a level needed for electronic manufacturing to lessen the need to process by batch and to enable and develop R2R analogs of these sheet-based processes
- Determine what production volume justifies R2R over sheet-based processing. The biggest struggle is high capital cost. Better technology and lower capital cost are needed. Technology advancement can produce greater capital investment. Desire higher quality of product.
- Address the general lack of process knowledge to support functional ink formulations and applications for advanced energy technologies

[5] Semiconductor Glossary, http://www.semi1source.com/glossary/default.asp?searchterm=thermal+budget
[6] C.-J. Yang / Energy Policy 38 (2010) 3270–3273

Table 1. Summary of Participants' Comments Related to Technology Needs, Manufacturing Challenges, and Investments for High-Value R2R Manufacturing

- Evaluate the need for integration of technologies/tools to devices with high speed and reproducibility
- Address considerations regarding waste/re-use useful life of materials focusing on low cost as they apply to Clean/Green Energy through rapid PV production. Examples: customizable size for building roof/wall, and environmentally enduring materials
- Focus on products and technologies that enable flexible PV, flexible battery, flexible electro-chromic film, and separation membranes
- Conduct industrial assessments to determine threshold batch to R2R
- Improve control of registering patterns with previously printed layers
- Further miniaturize feature sizes while maintaining throughput
- Investigate high resolution deposition for R2R for micro-electro-mechanical systems (MEMS)
- Evaluate the need for new R2R tools to support processing at lower costs yet allowing nano material integration. Batteries are R2R today, but yields are low; nanomaterials are hard to integrate. There is a lack of process knowledge to support functional ink formulation and application (materials that work with gravure, flex PV, etc.)
- Investigate high-rate production of cost effective layered barrier materials, such as those used in packaging of electronics materials and products
- Address challenges such as how to improve high energy intensity and low throughput of vacuum processing, metrology, quality, and process control

Rationale for Government Investment

- Consider capital investments vs. a business model to be self-sufficient. How does this happen? What applications should be addressed across this industry?
- DOE should focus on the hard problems, e.g., nanomaterials. The area of nanomaterials is exploding with new technology appearing at a very rapid pace. The research questions generated by these new technologies are complex and require working at corresponding finer levels of resolution
- The DOE additionality investment criteria are appropriate to assist many small developers with new materials but seems to ignore the need for competencies to scale

Other Participants' Comments

- Look for applications that are high volume or large area. How big is the socio-economic impact? Look at applications using up to 500 kw/hour. Batteries are 100 kw/h (85% cost of material). Investigate solar applications (99% yield). What are the technology challenges to overcome? Should DOE look at half-scale vs. full scale or predictive scale for common problems? In solving these problems, what is the realm of possibility? The research work should have an impact on how energy is made?
- The challenge at hand: find the key to prolific technologies such as high production levels, low costs, high batch quantities
- Deposition resolution is important to printing in batch. It is a matter of picking a facility to advance and further enable the technology that supports finer scale resolution
- Focus on rare materials. Lower Technology Readiness Levels (TRLs) vs higher TRLs. There is constant and continuous change of needs and variability in process control techniques. Establish a baseline of understanding as an objective.
- There are seven different $75 million institutes/industries for R2R; R2R needs to be highly successful for at least one range of applications.
- How do you move more quickly to new discovery of applications or a stage where you begin to see the numbers count? What's the right scope? Each year the needs/answers change.
- Investigate and integration technologies for toolsets to yield high speed, high ability
- Evaluate the transition between machine-based batch processing of materials to R2R manufacturing. What are the challenges? What adaptations are necessary? What are the complications? Does small business not have the resources?

Table 1. Summary of Participants' Comments Related to Technology Needs, Manufacturing Challenges, and Investments for High-Value R2R Manufacturing
• Address the waste and reuse of materials. What considerations are being taken for environmental damage? • Scaling larger is difficult. Investigate the need for technology and membranes to support applications such as flexible electronics at an affordable cost. Find engineering solutions that are most important to the process

R2R Process Deficiencies and Metrological Needs

QUESTION 2: What deficiencies and or needs exist today in R2R process equipment and metrology. What are the needs of individual industrial sectors? How do they differ between technologies and applications (e.g. alignment, registration, web speed control, surfaces, rollers, quality control, etc.); and what are the competing technologies and capacity levels which are cost competitive ("cost points," time and materials benefits) to assure R2R is competitive in manufacturing?

Table 2 summarizes participants comments on process deficiencies and metrological needs associated with previously R2R manufacturing needs, that when overcome, will better enable R2R manufacturing.

Table 2. Summary of Participants' Comments Related to Process Deficiencies and Metrological Needs in R2R Manufacturing
Equipment Deficiencies and Needs
• Address the following three areas: 1. in situ metrology; 2. R2R patterning with thin-film deposition; and 3. deposition tools. At present, these do not exist in the United States so we outsource procurement of tools. It would be better if the facilities were in here the U.S. • Address the need for 100% quality control inspection at high speeds in-line • Need 100% inspection levels. Small variations in many clean energy materials have a high impact in products like PV, batteries, and fuel cells • Investigate the need for uniformity of high kinetic reactant mixtures • Address process deficiencies in sheet-to-roll and the direction to the cross section
Metrological Deficiencies and Needs
• Identify areas that will broadly benefit R2R manufacturing • Address the challenge of online metrology with diversity of possible applications • Improve the current inadequacy of state-of-art support for in situ metrology which prevents manufacturing scale-up • Address the issue that high value materials often require functional, not just dimensional measurements in-line • If sensors are cheap, are we going to be overwhelmed with the amount of data produced? Will this large volume end up limiting the amount of analysis that can be conducted? Need to enable a range of sensor capability within structures, equipment, product, etc. and computational systems to support just such data collection. • Assess the relationship of defect vs performance as it applies to metrology • Investigate the stability of grain boundaries and microstructure in metals at the nanoscale
Competing Technologies and Capacity Levels
• Evaluate R2R competition such as tape casting versus batch-plate deposition • Address the need for new R2R metrology by considering what is available competing technologies • Investigate the need to enable the ability to process at one to two atomic levels per seconds, such as accomplished in Atomic Layer deposition (ALD). • Develop metrology that meets the need to control thickness uniformity (non-uniformity), surface smoothness, and film density • Address economies of scale: R2R vs batch for different business sectors
Other Comments
• Evaluate the appeal of application measures and benefits. The metrics for R2R manufacturing and the resulting benefits should be evaluated to determine if R2R manufacturing would be preferred, or have a greater appeal, than another comparable process; industry needs to have means to evaluate the suitability of any given technology platform versus another. • Address the biggest challenge of enabling real-time metrology in-line on R2R process platforms

Table 2. Summary of Participants' Comments Related to Process Deficiencies and Metrological Needs in R2R Manufacturing

- Identify an application that could drive technology forward as a potential means to bring programs into private sector (feature size wish list), e.g. need to be able to report optical clarity of film
- Investigate maintaining constant web tension on devices that have competing processes to R2R
- Assess what industry standards are needed to move forward with R2R manufacturing. There are no standard tools in this industry. Companies have their own custom processes/tools
- Resolution of metrology quality standards will give R2R a competitive edge over batch processing
- Determine what is needed to evaluate economies of scale for various industries and be specific for each industry and market
- Determine if the institute should be responsible for finding out what is out there. How fast can the data be found? Is there a better alternative for reducing risk? One objective for an institute might be to analyze various applications and processes that compete with R2R manufacturing and determine if there is an alternative method that would reduce the risks associated with R2R manufacturing (such as answers provided by a detailed roadmap for a given technology)
- Address the issue that high temperature cleaning is difficult because each layer needs to be clean. The problem is not speed
- Develop enhanced registration capability between layers
- With regard to sheet or batch vs. R2R processing, in a realistic environment, you will not see a large amount of material loss (ex: evaporation) in a continuous batch processed by an in-line system
- Small suppliers are not willing to invest because they might not have the resources. It could be because of the high risk. If investors are willing to invest, then they need to have a license to technology and manufacture. Unusual equipment is not readily available and the high cost makes it impossible to buy just to explore.

R2R Quality Systems and Synergy

QUESTION 3: What are some quality systems and other technologies or capabilities that could be addressed by an institute? How are these envisioned and/or necessary to meet the needs of a commercially-viable, high-capacity, high-value R2R process? How would these systems, technologies, or capabilities provide a full manufacturing complement that would be adaptable to multiple industrial sectors or applicable only to a singular technology area? How would they impact clean energy goals?

Table 3 presents participants' ideas for the elements of a quality system and the synergy needed to achieve a quality system that would have a high impact on Clean Energy Goals.

Table 3. Summary of Participants' Comments Related to Quality Systems and the Synergy Needed to Adapt to Multiple Industrial Sectors or Single Technology Areas Having High Impact on Clean Energy Goals
Quality Systems, Technologies, and Capabilities for High-Value R2R Manufacturing
• Focusing on developing quality systems may be a waste of time. Industry should do that. • Evaluate the sponsorship of industry standards committees that would be best to focus on quality control • Address the key quality characteristics that must match existing batch/plate processes • Evaluate the need for better specifications on the R2R protocol • Evaluate process variations for application of R2R. Many novel/high-value materials tolerances are not well established because the actual functional effect of process variation is not known • Investigate how to maintain a constant web tension on a brittle material, layer, or substrate • Evaluate condition-based monitoring, such as used in support of the grid[7] • Leverage traditional print and platemaking vendors • Evaluate DOE sponsorship of an industrial standards committee
Impact to Clean Energy Goals
• Establish how to allow R2R use of highly "kinetic-reactant" materials, alleviating the need for vacuum process chambers and ovens • Evaluate the elimination of vacuum, lower heat, reactors vs. furnace which represents major positive impact on clean energy manufacturing • Focus on clean energy or American competitive position or both • Investigate the elimination of equipment cycling which enhances the life of equipment

[7] http://www.masteringthesmartgrid.com/solutions/condition-based-monitoring-cbm

DOE Focus and Appropriate Mechanism for High-Value R2R Manufacturing

QUESTION 4: How should "high impact" technology development, that would transform the marketplace compared to the status quo, be initially focused so that DOE funding and openness results in enduring economic benefit to the United States, particularly for the manufacturing sector? Would a 5-year, multi-participant, industry-oriented institute be the appropriate mechanism to address high value R2R manufacturing? (for example, focused on broad problems and be open to new ideas <u>or</u> new approaches and new performers; high-cost/low-volume products <u>or</u> low-cost/high-volume products; clean energy materials <u>or</u> have a broader reach but still have a focus on clean energy materials?)

Table 4 lists participants' ideas on how DOE should focus efforts and proposed mechanisms that would be appropriate to achieve high-value R2R manufacturing.

Table 4. Summary of Participants' Comments Related to DOE Focus and the Appropriate Mechanism for High-Value R2R Manufacturing

Focus on "High-Impact" Technology Development

- Integrate atomic layer deposition into the suite of available processing capabilities.
- Promote flexible products that enable multiple applications and bigger market opportunity.
- Consider flexible PV to enable building integrated PV (BIPV) solutions; flexible batteries to further enable adoption of "wearable devices; flexible "electrochromics" film to address the "retrofit" market; and low cost membranes for the gas, water, ion separations and chemical processing industry.
- Invest broadly so existing R2R manufacturers see benefit to productivity
- Develop alternate treatment and testing processes that ensure functional performance of components. Today treatment is only done in batch

Appropriate Mechanism (if an Institute, where should efforts be focused?)

- Evaluate the transition needs of moving from current state-of-the-art high cost/low volume technology to lower cost/higher volume technology platforms for large scale energy storage applications
- Focus on technologies that are 'leapfrogging' over current methods. In general, intellectual property (IP) sharing gets easier if it jumps ahead. Address how research can be sustained if cost-share funding is not available? Being first to market is important.
- Focus on a set of R2R process technologies that can significantly impact both advanced technologies and products, such as PV flexible counter electrode technologies and more mature product areas, such as those used in current thin film deposition, spray coatings or gradient/multilayer coatings, or lithography/printing
- Evaluate use of alternatives to current low greenhouse gas emissions (LGGE) technologies in the existing industry vs emerging LGGE technologies

General Comments

Table 5 provides participants ideas and comments that apply to R2R needs and challenges to make it more competitive in the United States.

Table 5. Summary of Participants' Comments Related to Competitive Viability of High-Value R2R Manufacturing
Factors making R2R manufacturing more viable as a competitive technology for production in the United States
• Retain the competitive advantage that R2R manufacturing offers. Current competitive advantages of R2R processing include high production rates and yields because devices can be automatically fabricated in mass quantities. The effective yield is a function of quality and the systems used to determine such prerequisite properties and function. • A variety of manufacturing steps may also be accomplished using R2R processing. For example, with flexible electronics (in addition to laying down circuit patterns), such steps as die cutting, laminating, placing labels, cleaning, and more may be performed simultaneously. Heat sealing and application of a variety of coatings may also be included in a single roll-to-roll processing operation.[8, 9] • Address the various economies of scale. The current technique used in R2R processes uses economy of scale to help reduce the cost of manufacturing. Although initial capital costs can be high to set up such a system, these costs can often be recovered through the economic advantages during production.[10] • Focus on engineering solutions that are not influenced by industry competition and intellectual property. • Increase the willingness of industry to share information on company processes • R2R advancements would benefit from involvement of the National Laboratories. At a minimum, having test beds or MDFs available to evaluate processes would be useful to industry to allow testing prior to capitalization of needed high-cost equipment. This same involvement would enable advances in metrology design, use, and computational services. • Specific challenges are quite complex. Fundamental equipment required to support operations has been available to the industry for years. However, there remains an ever increasing requirement for tools to enable faster speed processing at greater width dimensions, at finer resolutions and size scales with precisely aligned multilayer process capability. • With the R2R introduction into a manufacturing-line, the economies of scale processing becomes much less energy intensive, raw material use involved in equipment "set-up" and "shut-down" is less, scale-up to higher capacity is easily facilitated, etc. • Introduction of this platform technology supports plant automation , which in-turn creates the need for a more highly trained and smaller workforce labor requirement • Advances in metrological and quality systems designs need to consider and establish defect impacts on performance for given products • Any standards for products from R2R need to be equivalent to standards from batch processing. An NNMI should sponsor committees involved in establishing standards focused on process, metrology and equipment • Any NNMI Institute needs to be broad enough to attract a wide range of stakeholders and support existing and emerging technologies areas

[8] WiseGEEK Clear Answers for Common Questions, p.1, http://www.wisegeek.com/what-is-roll-to-roll-processing.htm
[9] Wikipedia, Roll to Roll Manufacturing Process
[10] Ibid., same page.

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4. ADVANCED MATERIALS MANUFACTURING (AMM)

Introduction

In June 2011, the National Science and Technology Council (NTSC) announced the Materials Genome Initiative (MGI) for Global Competitiveness. The MGI is a multi-stakeholder effort by government agencies, industry and academia to develop an infrastructure to accelerate advanced materials discovery and deployment in the United States.[11] AMO conducted a series of technical team meetings in March 2014 comprised of representatives from AMO and the Vehicle Technologies Office (VTO) to develop topics for potential institutes that might support the MGI. In addition to the six criteria for work established by the National Network for Manufacturing Innovation (NNMI)[12] (high impact, additionality, openness, enduring economic benefit proper role of government and the appropriate mechanism), specific institute characteristics were offered:

- Assess the progress in transitioning a technology from Technology Readiness Level (TRL) 3-4 up to TRL 7
- Evaluate the progress of transitioning technology based on market pull
- Focus assessment on transitions of cross-cutting technologies as much as possible, e.g. technology that serves multiple sectors and not a single industry, and
- Develop a logical/compelling rationale for having a shared facility as a resource used by all of industry and academia.

Two areas of interest addressed by the team were as follows:

- MGI – Evaluate complementary opportunities for what is publically available. Current MGI efforts by other organizations typically focus on collecting fundamental data to support integrated computational materials engineering (ICME). ICME data cover thermodynamics, kinetics, and models and computational tools for material development.
- Nano-manufacturing – Assess world-wide efforts for nano-materials and nano-devices manufacturing. Examples of nano-technologies include quantum dots, nano-electronics, nano-particles, and nano-crystalline metals.

The March 2014 results were used as a basis for specific topic areas of interest included in a Request for Information (RFI) titled "Specific Clean Energy Manufacturing Focus Areas Suitable for a Manufacturing Innovation Institute" released on August 29, 2014.[13]

However, further public and private sector input was still needed to 1) identify advanced materials manufacturing (AMM) technology areas that might benefit as part of an organized materials manufacturing innovation institute, and 2) assess the potential contribution an institute could make on domestic clean energy manufacturing competitiveness. The purpose of the AMM breakout session was to

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[11] Materials Genome Initiative for Global Competitiveness, Executive Office of the President, National Science and Technology Council, June 2011.

[12] Johnson, Mark. "U.S Advanced Manufacturing and Clean Energy Technology Challenges." Presented at the AMO Peer Review on May 6, 2014. Accessed November 6, 2014. http://energy.gov/sites/prod/files/2014/06/f17/AMO%20Overview%20(Organization,%20Strategies,%20and%20Initiatives).pdf

[13] Department of Energy, Request for Information, "Specific Clean Energy Manufacturing Focus Areas Suitable for a Manufacturing Innovation Institute, DE-FOA-0001158, August 29, 2014.

discuss, brainstorm, and identify AMM-related challenges, opportunities, and appropriate mechanisms for integrating MGI toolsets and expertise.

The AMM breakout session focused on five key areas:

- Experiences/lessons-learned in applied materials development
- Gaps in current tool sets and resources and possible solutions
- Existing resources and leveraging opportunities
- AMM core infrastructure and leveraged partnerships, and
- AMM centralized institute and/or distributed consortium.

Five focused discussion questions were prepared in advance. Individual participant's views and responses were captured using a compression planning and brainstorming process which draws on small groups to identify, prioritize, and/or analyze information in a compressed time period using the focus questions and story boards for a real-time capture of ideas.

Experiences/Lessons-Learned in Applied Materials Development

FOCUS QUESTION 1: The application-driven approach aims to accelerate the material design/advanced materials manufacturing process. What are your experiences, good and bad, using computational/experimental tools (including 'high-throughput' methods) in application-specific materials development efforts?

Table 1 summarizes participants' comments on a number of experiences and lessons-learned in applied materials development at their companies or agencies using quantitative metrics for each category of **more successful**, approaching 90%: **mixed results**, or 50% chance of being successful; or **less successful**, a success rate for detecting defects approaching 5% in terms of performance and development time, when appropriate.

Table 1. Summary of Participants' Comments Related to Experiences/Lessons Learned in Applied Materials Development

Structural/Environmental Materials - Computational

More Successful (Positive)

- Extend computational modeling of processes (casting, welding) to additive manufacturing for metals and alloys. Address solidification models. Identify defects in parts. Evaluate the challenges and needs to link a process to its performance using microstructure information.
- Research the use of extensive computational design of materials in multiple dimensions and scales
- Evaluate novel sensor design and computational optimization

Mixed

- Assess the need for an institute that is focused on advanced electrical conductor manufacturing
- Address the challenge of bridging gaps between material design and micro/macro design
- Survey the business sector for tool, software, and collaborative application development. Move forward with solutions for bulk materials that perform poorly due to defects/interfaces/devices.
- Evaluate the structure for industrial automation equipment and power
- Evaluate the need for an institute focused on advanced electrical conductor manufacturing

Less Successful (Less Positive)

- Identify gaps associated with the extracting information that is otherwise lost knowledge from remnants and "failures."

Structural/Environmental Materials - Experimental

More Successful (Positive)

- Assess the impact of the following for possible inclusion in an AMM: coating development for structural/environmental materials is 1) increasing relative to temperature stability, 2) increasing or decreasing in the case of wear resistance depending on the application, and 3) decreasing with respect to corrosion.
- Evaluate a high temperature approach to develop and apply research for 1) novel high temperature alloys with oxidation resistance, 2) incorporating process modeling to expedite a data library design that includes costs, and quantities, and 3) other data that includes energetics with phase formation
- Invest in combinational materials development
- Investigate high throughput bulk materials synthesis and characterization; for example, combinational arc melting
- Investigate high enthalpy thermoelastic materials with the potential for decreased cost, increased latent heat, increased fatigue life, and increased capacity
- Lead a thrust effort on functional materials, structural materials, high temperature alloys. Focus on results that are more relevant to commercialization
- Focus on TRL 1-2 capabilities that are maturing

Table 1. Summary of Participants' Comments Related to Experiences/Lessons Learned in Applied Materials Development

- Support strong interaction between theoretical and computational modeling (TCM) and experimentation
- Ensure a balance between accuracy and speed in applied materials development
- Assess the need for a multiple property searches to get targeted functionalities
- Monitor advances in rapid component/device screening
- Evaluate common tool sets for classes of materials
- Assess the need to go beyond perfect bulk systems to include defects and multi-phases
- Investigate the development of a vanadium oxide phase transition film

Mixed

- No comments were given under this category.

Less Successful (Less Positive)

- Develop an institute where underutilized expertise such as data analysis techniques and data mining techniques can be developed

Functional Materials/Interfaces - Computational

More Successful (Positive)

- Use distributed computing, ontologies, and informatics to merge and do data analytics on real world time series data on photovoltaic (PV) power plants with laboratory-based accelerated studies
- Explore data mining as a method to meet computational needs; e.g. using data mining alone and not first principles. For example, a new class of thermoelectrics was discovered and demonstrated on a laptop in less than two months.
- Investigate the lack of connection between computational output and experimental tools like time, scale and property and key performance characteristics (e.g., in ability to predict properties that are relevant for device design). Evaluate high throughput experimental bulk combinatorics versus broad synthesis capabilities.
- Emphasize investigations of functional materials computational/multi-scale modeling and experimental validation over manufacturing formulation design the latter of which is of more interest to industry
- Provide a streamlined and computational approach for development of non-platinum catalysts for fuel cells and facilitated discovery of non-platinum catalysts by identifying specific and secure formulations. More importantly, account for the important effects of materials interfaces not identified in a specific synthesis.

Mixed

- No comments were given under this category

Less Successful (Less Positive)

- No comments were given under this category

Functional Materials/Interfaces - Experimental

More Successful (Positive)

- Emphasize the tenfold increase in power density and life for proton exchange membranes (PEMs) for fuel cells.
- Address improvement opportunities such as "need for speed!" with solutions like in situ certification.
- Assess the need for combined high-throughput experimentation (fast device proto-typing) for devices (multi-layered stalks) to overcome interface/defect/integration challenges on manufacturing relevant tools
- Develop methods for performance targets that will accelerate technologies more than twice current capabilities for PVs, batteries, light emitting diodes (LEDs), smart glass, and power electronics
- Develop new functional materials for insulation and power products such as transformers
- Develop better resources for informatics. During experimentation, in addition to discovering new materials, produce results looking at material compositions, structure, and property relationships of systems. Use these results as blueprint for future experiments.
- Focus on composite materials qualification costs. These costs are the limiting factor in the development of next generation materials.
- Investigate advance materials that comply with regulations for ozone depleting substances (ODS)

Table 1. Summary of Participants' Comments Related to Experiences/Lessons Learned in Applied Materials Development

- Improve upon incremental changes in manufacturing processes to include thermal treatments, different forms of materials, and thicker metals
- Organize technology development by phase shifts that correspond to the three phases of semiconductor manufacturing technology (SEMATECH) by adding one and a half years
- Investigate the need for critical materials screening
- Assess iterative development at pilot line level
- Accelerate multiple advanced materials directly into manufacturing of multiple energy technologies (PVs, energy efficient glass, LEDs, batteries) using high-throughput experimentation (HTE)
- Reduce development time from what has historically been 18 months down to a goal of 5 months
- Work hand-in-hand with product development on a specific product
- Assess selected combinatorial experiments for understanding formulations for photoresists
- Address the challenge of gradient-influenced local effects on advanced materials
- Investigate experimentation and simulation of functional materials for electronic applications. Typically the time from research to manufacturing is 10+ years for most materials. This 10 year period includes lots of research; but it was the materials advancements during the research period that enabled the semiconductor industry to substantially shorten the cycle time between research and manufacturing. As an example in nine months catalytic materials were both designed to exceed original requirements, and validated for cost-effective manufacturing.
- Address the challenge of scale-up and testing of advanced materials in relevant environments. Did the test environment in the laboratory or in the pilot plant scale up differ from the operational environment during full scale production? For example, were test conditions for elevated humidity and extreme temperatures identical to the production environment?
- Determine if time-to-market can be shortened for both high volume and 'to scale' manufacturing. Can the costs for raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture an end product, along with the overall cost of operation, be reduced?
- Investigate atomic layer deposition (ALD) as an advanced manufacturing process to apply quantities of materials from 100 grams or more, to an area of 10,000 square meters. Determine experimental methods development, materials expertise in area of materials for PV, and materials characterization requirements.
- Assess industry experience in developing, using and enabling the industrial acquisition of combinatorial and high-throughput measurement approaches for next generation materials research and development

Mixed

- Make more use of computational methods for functional materials/interfaces
- Apply synchrotron structure and chemistry characterization tools, especially in situ and operando spectroscopy, to processes for advanced materials
- Investigate functional materials, experimental methods, and interfaces for each application (PVs, storage, catalysis)
- Include a means to access DOE user facilities more easily
- Find ways so EFRCs are more directly helpful to industry
- Invest in functional materials and experimental advanced membrane development for heating, ventilation and air conditioning (HVAC) (dehumidification applications including leakage/durability). Consider different research organization models that support manufacturing business units. Improve the process (beyond just laboratory-scale data calls) to reduce the time for the development of advanced materials used in clean energy applications, specifically, in applications like batteries where the end-product performance is critical.

Table 1. Summary of Participants' Comments Related to Experiences/Lessons Learned in Applied Materials Development

Less Successful (Less Positive)

- Investigate a means to advance gradient/thin films into real-world materials and devices, e.g., non-platinum catalysts for fuel cells, which might include adequate electrochemical screening tools
- Investigate a method for data sharing. Increase sharing of all data among partners
- Address issues going from computational to operational. For example, with university computational approaches for catalyst development the supply chain is not mature enough to support batch-batch operations.
- Address issues regarding scale-up and manufacturing costs for advanced materials. Particularly address suppliers who cannot scale within cost constraints for manufacturing of new materials such as 17/7-Precipation Hardened Condition C (Hard Rolled Temper 17/7 Chromium - Nickel 1 % Aluminum) Stainless Steel, Aluminum-Lithium, aramid aluminum laminate (ARALL), 7475-series aluminum alloy, and beta-titanium alloys.
- Include a development process that allows for the many cutting-edge manufacturing technology advances are generic and incremental and not innovative and transformational

Other Comments

More Successful (Positive)

- Investigate biological processes to synthesize structural materials, fuels and chemicals
- Investigate synthesis and functional testing of materials, interfaces, and novel optoelectronic devices/sensors
- Make more use of organized industry-pull during early stage commercialization. Make more use of industry members and related consortia specifically in areas such as energy storage, desalination, and catalyst-designed synthesis.
- Assess the potential of industry partners with capabilities to bridge technology development with industrial-scale manufacturing and commercialization of advanced materials

Mixed

- Address the challenge of missing data bridges especially concerning composition, synthesis, structure, and functionality using data mining (unsupervised; machined learned)

Less Successful (Less Positive)

- Devote resources for database development

Gaps and Access Limitations in Current Tool Sets and Expert Resources

Question 2: What are the gaps and access-limited challenges in the advanced experimental tools (e.g., synthesis and characterization tools) or computational/ modeling tools (including high-throughput methods) that are available for solving application-specific materials development problems? What, if any, additional development, validation, or integration/interoperability work would be most beneficial to accelerating the development process?

Table 2 summarizes participants comments on gaps and access limitations in current tool sets and expert resources associated with applications specific to AMM.

Table 2. Summary of Participants' Comments Related to Gaps and Access Limitations in Current Tool Sets and Expert Resources

Structural/Environmental Materials

Computational tools and expertise: multi-scale, ICME, etc.

- Evaluate structured intellectual property (IP) in constructing contracts that facilitate access, are more cost effective, and provide timely access to data
- Evaluate current systems that do not allow feedback into models

Information and data (deficits & surplus): informatics tools and expertise

- Identify research gaps for using the experimental (environmental) method versus a trial-and-error method (reality)
- Consider/understand interfaces, surfaces, defects, impurities, not just the material alone but also in the interfaces connecting materials in components in devices
- Define the criteria for successful analysis of large data, use of predictive methods for processing and synthesizing large amounts of data, and fast testing of components/devices in general
- Information gaps in advanced material properties, scale-up requirements, and manufacturability exist when you have to work with big industry at early TRLs
- Assess gaps between the integration of data analytics with 1) data generation (characterization), 2) on-the-fly (nearly real time), 3) unsupervised machined-learned accuracy, 4) university/robustness, and 5) computational efficiency. Big data equates to knowledge.
- Integrate theory/simulations and experiments with database building. Use the design of experiments to characterize the "right properties" that apply to a device's ultimate performance in a combinational manner.
- Find solutions to issues involving IP management, research publication, and separation of information related to IP ownership and unique models
- Evaluate the gap in proprietary information used for computational analysis. Information must be available in real time and efficiently obtainable. Focus on getting information exchanged and into the open for use by others.
- Take steps to protect IP ownership and confidentiality, when appropriate. Establish a "non-competitive" core team. Assess the gap between IP and knowledge transfer because companies generally will not divulge the most sensitive information about their research.

Experimental Tools and Expertise: Synthesis, Characterization (including high-throughput, combinatorial, etc.)

- Assess the knowledge and semantics gap between material development, device synthesis, and experiment.
- Assess the gap between rapid and real physical properties characterization, e.g. fatigue, creep, corrosion, etc.
- Analyze the division between experiments and theory. A great deal of information is not transferred between theorists and experimentalists because it takes time for them to start understanding each other.
- Assess the gap for leveraging "remnants" (of research) which could potentially bridge the gap between "proprietary" and "broad access." This requires proper informatics and sufficiently reproducible process control.

Table 2. Summary of Participants' Comments Related to Gaps and Access Limitations in Current Tool Sets and Expert Resources

- Assess gaps for manufacturing structural materials: 1) scalability from tiny to tons and variability, i.e. understanding cost and capital constraints; 2) downstream manufacturing processes and the lack of rules for being producible (e.g., equipment, consumables, environmental health and safety, disposal/segregation, rework); and 3) people with skills and knowledge of new materials to solve issues.
- Assess the gap between high throughput make-measure-model tools and knowledge management tools used at the TRL and Manufacturing Readiness Level (MRL) 4 to 7.
- Assess the manufacturing gap in high turnaround that doesn't allow for regularity. There is a need for easy, on-demand access for some type of remote submission. Also, there is a need for access to specialty pieces of equipment for smaller companies.

Functional Materials/Interfaces

Computational Tools and Expertise: Multi-Scale, ICME, Etc.

- Assess the computational gaps and needs for reduced order models, and fast emulators for process modeling (specifically as new processes are developed). High-fidelity multi physics models are slow. Validate with experiments to identify missing physics and make models predictive using large data analysis for visualization.
- Provide access to in situ characterization techniques to test catalysts/metals in real environments, access to three-dimensional printing/bulk synthesis techniques, and computational tools linking design for testability (DFT) to knobs on a sputtering system.
- Provide data analytics capable of handling qualifying data sets.
- Assess a computational materials gap for the validation of experimentation within industries. This would allow for more relevant manufacturing
- Unlike research, current processes and computational tools don't allow for results feedback

Information and Data (Deficits & Surplus): Informatics Tools and Expertise

- Investigate the need for linking techno-economic evaluation and roadmapping to coordinate a material development cycle with the product development cycle and identify insertion points
- Assess the following gaps: 1) Multi-scale model integration (from formulation to manufacturing) and validation (industry's confidentiality concern); and 2) material functions versus life-cycle-based sustainability assessment (model and validation).
- Link the previous effort with design/physics modeling, in-situ characterization, and in-situ control as an end-to-end tool chain, e.g., open modules available to the whole institute
- Address issues that could enable access to competitors developed materials, e.g., make the knowledge of critical characteristics of legacy materials that inform and enable new materials development available
- Assess an information gap among highly confidential companies. Does a lack of sharing information indicate what is needed for development?
- Assess the knowledge gap between data integration challenges and obtaining a critical understanding of material provided by different sources. A challenge for university, startups, and small business is gaining access to quality tools and information that is relevant as well as access to expertise
- Address the management gap between university-style research and industry-style consulting

Experimental Tools and Expertise: Synthesis, Characterization (including high-throughput, combinatorial, etc.)

- Assess the lack of testing in relevant environments. For example including integration in a product or product-like approach and accelerated life-testing
- Address access/use of a model for synchrotron tools that are correct for regular use in high temperature experiments. To be a useful tool remote experts are needed.
- Address the gap of industry versus university timescales and harmonize management approaches. Address the gap in sustained, managed multi-disciplinary research, e.g., long-term nature of research is incompatible with industry timing. For example, the different approaches to understanding the metal/electrochemically active non-metal interface for batteries and catalysis. Also there is a large gap between laboratory work and a production facility for large area, high performance, multi-scale sensors, as well as biosynthesis and other materials.

Table 2. Summary of Participants' Comments Related to Gaps and Access Limitations in Current Tool Sets and Expert Resources

- Assess the quality of process tools that are manufacturing relevant, such as cluster tools and manufacturing quality/control non-gradient tools (very difficult to control process and interfaces)
- Create a dedicated and focused common co-location to provide access to an expertise core and to develop a critical mass devoted to theory, experiment, application, and product
- Address a testing/experimentation gap for fatigue screening, and scanning. Currently, all have to be done individually. It would be more efficient to be able to do these in bulk; however, there is a need for tools for experimental and long term testing as well as the fast testing of components and processes.

Other Comments

Computational Tools and Expertise: Multi-Scale, ICME, Etc.

- A "Library" of tools is needed to identify best investments. Advanced modeling is required to shorten development time and additional computing power is needed to support information and data gathering, analysis, and storage. Managing big data and computing power require experimentation tools and expertise.
- Create or make available an easily searchable materials database
- Create or make available a scheme for commonly used materials data (i.e., process, performance. composition)
- Create or make available databases that are broad, integrated, and accessible
- Develop provenance (chronology of ownership) for data
- Accessible data and proprietary control are not mutually exclusive, i.e., research data does not have to be proprietary in all cases and can easily be made available in open publications
- There is a vast amount of data that is not proprietary but is so widely dispersed as to be unusable. Develop a method or process that allows as much data as possible to be collected in a single data base or web location. Include real-world conditions/performance and defects with modeling simulation and predictive tools.
- Find skilled experts. Find a common ground for conversations among different industries. Improve access to educational opportunities.

Information and data (Deficits & Surplus): Informatics Tools and Expertise

- Provide more training on modeling packages for design engineers
- Address the data analytics gap between large data analysis and predicative processing. Access to characterization techniques is needed in real time and in the appropriate environment. Investigate how to access proper equipment/expertise and how to handle large data sets with quality results. Address accessibility to data and proprietary control. Find a way to validate what is good data versus bad data and properly transcribe data so it can be used**.**

Experimental Tools and Expertise: Synthesis, Characterization (including high-throughput, combinatorial, etc.)

- Investigate different approaches to manufacturing marketing program management, and improve access to subject matter experts in engineering coatings, robotics, roll-to-roll manufacturing, process modeling, and structural models (finite element (FE) analysis tools) which can result in reactive polymer production controls.
- Need an experimental materials' industry "contract" to outline what will be considered the "bottom line" for providing access to and sharing of information and still protect customer IP. Ease customer doubt. For example, equipment and resources of big companies could be shared with smaller companies which could leverage remnants of information as open source data.

Existing Resources and Leveraging Opportunities

Question 3: What are the pros and cons of existing efforts at multiple U.S. institutions developing fundamental material data, property data, advanced materials computational tools, high throughput characterization methods, and deep knowledge about the relationships between composition, processing, structure, and properties. Where are there gaps that may be addressed with the proposed DOE approach?

Table 3 presents participants' comments regarding existing resources and leveraging opportunities available at various U.S. institutions and their abilities or gaps in their abilities to support an AMM approach.

Table 3. Summary of Participants' Comments Related to Existing Resource and Leveraging Opportunities that Would Support an AMM Approach
Structural/Environmental Materials
Application-driven manufactured materials • Look at developing a high throughput melting system for bulk sample synthesis followed by auto-load differential scanning calorimetry/ thermo-gravimetric analysis (DSC/TGA) • Evaluate scalability of processes, e.g., fabrication up to the kilogram scale • Determine the appropriate pilot scale in an AMM and how to connect rapid tools with large-scale processing. Address the need for validation of the process and if it exceeds MRL 4 • Assess the challenge of moving MGI methodology from just materials into devices at a TRL 4-7 level
Cross-cutting; multi-scale, multi-physics • Assess the leveraging opportunity for application driven combinatorial examination of polymer and composites at process scale similar • Look for leveraging opportunities similar to an industrial consortium for using neutrons • Address needs in informatics to include education about how to combine data science and material science; theory and experimentation. Address the need for cross-cutting data and feedback logs among TRLs/MRLs. All data must be included and vertically integrated to represent compounds, structures, and devices.
Fundamental; atomic to molecular scale • Investigate the use of synchrotron beam lines and neutron reactors for advanced materials research. By using synchrotron beam lines and neutron scattering reactors, advanced material structures and their tomography that were previously "invisible" at the atomic and molecular level, and three-dimensional images of heterogeneous materials can be revealed. These images are not accessible to conventional tomography based on x-ray tubes. • Employ modeling software for library design and optimized for energetics data
Functional Materials/Interfaces
Application-driven manufactured materials • Locate an existing resource that can be used to accelerate new materials and existing materials in new combinations and integrated into devices • Provide a unified system for storing and representing materials data • Address a fundamental gap of application-driven manufactured materials at the user facilities. Connect with National Laboratory user facilities research and develop cross-cutting technologies such as lightweight metals, composites, and critical materials that never make it into a specific application.

Table 3. Summary of Participants' Comments Related to Existing Resource and Leveraging Opportunities that Would Support an AMM Approach

Cross-cutting; multi-scale, multi-physics

- Look for useful interactions with DOE user facilities doing advanced materials research; evaluate the ability to incorporate reliability programs in PV, solid-state lighting, and hydrogen fuel cells
- Make computation modeling software available that contains a suite of codes at multiple scales: DFT, continuum mechanics, heat transfer, meshing, etc.
- Assess facilities that can provide capabilities for computational modeling and simulation and sustainability assessment (from material formulation to end product manufacturing and use phase for nanocoatings)
- Assess the use of high-throughput catalytic reactors
- Assess facilities with high-throughput methods for monitoring metallurgical and oxide phases in high temperature alloys
- Form an institute which serves as a "materials task force" for other centers, hubs, and EFRC's

Fundamental; atomic to molecular scale

- Address the issue of IP and balancing proprietary versus open source data in such a way that companies can become comfortable disclosing all information about the problems they need to solve. Determine methods to leverage "remnants" or legacy data sources to reduce the IP gap and address concerns about "critical" IP information that could be released to "competitors" in industry and during research, development, and procurement.

Other Comments

Application-driven manufactured materials

- Ensure an AMM institute is open to everybody
- Improve the process which allows industry and manufacturers to engage with the national laboratories to maximize collaboration
- Develop a process that allows small companies and startup production facilities to easily integrate or combine existing materials and systems to solve DOE material application problems rather than wait on a new technology to be discovered
- DOE national user facilities have "metrologies" for bulk material production, material interface issues, and application of in situ operando spectroscopy. Address the following issues that could be solved by DOE national user facilities: a) material throughput is low because the current metrology in use is inadequate on the production line, b) effective metrology solutions are slow to achieve, and c) IP is a concern when trying to obtain state-of-the-art metrology devices.
- Connect outputs to experimentation, especially at the device level and higher levels using MGI based computational engines

Cross-cutting; multi-scale, multi-physics

- Assess the gap between computational predictors and experiments
- Assess the need for process condition optimization
- Investigate in situ device level characterization and downstream insertion of a combinational approach
- Address the lack of accessibility to specialized tools (characterization and synthesis)
- Assess the gap between microstructural property and macroscopic property
- Address the lack of modeling of properties and feedback from experiments

Fundamental; atomic to molecular scale

- No comments were given under this category

AMM Core Infrastructure and Leveraged Partnerships

QUESTION 4: What core infrastructure components and specific relevant capabilities/tools would be required for a central facility or institute to support an AMM-based approach to various materials challenges. How would they compare to distributed model leveraging or expanding on existing capabilities? What is the availability and ease of access of advanced computing/experimental tools from specific institutions relevant to application-driven problem? What AMM framework --potentially including central core capabilities and expertise, leveraged partner resources, and coordinated linkages with MGI and other materials R&D efforts -- would be best suited to build a versatile and expandable R&D community in accelerated materials development? Specifically for applications related to clean energy, uniting, curating, and coordinating resources in a way that preserves intellectual property and maximizes the benefits for U.S. industrial competitiveness?

Table 4 lists participants' opinions of core infrastructure and leveraged partnerships that currently support an AMM approach.

Table 4. Summary of Participants' Comments Regarding AMM Core Infrastructure and Leveraged Partnerships
CORE: Management Tools & Expertise (including scientific, manufacturing, intellectual property, etc.)
• Look for access to critical expertise such as some co-location of these valuable elements and tool makers/processes • Investigate external resources for the broader MGI and other materials research efforts for an AMM institute
CORE: Computational and Modeling Tools & Expertise (including high-throughput)
• No comments were given under this category
CORE: Experimental Tools & Expertise (including combinatorial and high-throughput methods)
• No comments were given under this category
CORE: Materials Expertise in Clean Energy Materials Classes
• No comments were given under this category
CORE: Data and Informatics Tools & Expertise
• No comments were given under this category
PARTNERS: Toolset Developers and Integrators
• Actively involve product developers in the research. Successful toolsets are not separate teams; but instead, highly integrated group of people working together • Streamline negotiations up front with DOE National Laboratories and create real partnerships. Negotiate agreements and settle on IP up front by looking at the possibility of using an "access agreement" for everyone. • Identify what a successful institute should look like from an experimental standpoint and for a partnership. Identify some number of technologies that will move forward and be invested in by companies. Consider commercial metrics as well as science metrics with a target of having results to show within the first six months.

Table 4. Summary of Participants' Comments Regarding AMM Core Infrastructure and Leveraged Partnerships

PARTNERS: Clean Energy Application Developers and Manufacturers

- Make institutes accessible so manufacturers can bring a problem to an institute as a "general" issue without sharing IP
- Address the need for flexibility so small companies are able to come and go and join or leave as necessary
- Identify the aspects of an institute that will help industries move forward faster such as how to build partnerships and what features make industry want to be a part of it. Address how the institute could help meet industry's needs in the short term. (Research and development models do not always produce the same output from a given starting condition or initial state, therefore, actual data must be used to fill in gaps for material properties and production parameters necessary for manufacturing products with advanced materials.)
- Make data and tools/toolsets available to for manufacturers along with networking and technical expertise
- Develop metrics that demonstrate progress in transitioning technologies to solve a material problem without having to expose IP to everyone and without having to give up too much information
- Look at the possibility of a tiered membership program; for example, the winner of a contract would receive a subsidy to join certain groups/consortia and be sustainable. Develop a material center where products can be accessed quickly to solve problems without having to be a core integral member of a consortium, which is a problem for small business and startup companies. Look to other models for ideas for tiered membership and tiered benefits.
- Explore ways on how to satisfy all levels of people and get new members into a consortium. For example, a prospective member has to meet minimum requirements then submit a proposal. A board (founding members/core members/charter) would then review and decide if there is a need to accept the member.
- Find a way to achieve sustainability in seven to ten years for an institute through a tiered membership and incorporate fee-based membership post sustainability which has the possibility of producing spinoff companies
- Investigate a fee for service type institute that would not be in competition with companies. Verify that materials and/or processors are not available in the private sector. Encourage members to pool resources and expertise.
- Address non-compete rules for the private sector which are different for DOE and DoD and make sure the rules are available
- Address how prototyping could be done with the companies who come in with a problem and if prototyping capabilities at the institute are needed
- Target a time frame of three to four years which would allow for a more general approach for achieving success. At the end of each year, assess the results
- Develop a tool set that would allow digitalization to share and show materials and data. (These should be short term successes for industry.)
- Investigate options for companies to pay for and own solutions to their project/problems. Consider a members-open IP hub model with a wheel-like spoke for industry-owned IP projects

AMM Centralized Institute and/or Distributed Consortium

QUESTION 5: Does an AMM centralized institute and/or distributed consortium make sense, and if so, what does it look like?

Table 5 provides participants ideas and comments regarding an AMM centralized institute and/or distributed consortium.

Table 5. Summary of Participants' Ideas and Comments Related to an AMM Centralized Institute and/or Distributed Consortium

What does it look like?

- Define a mission clearly in order to make the most of all investments
- Focus on membership tiers and fees
- Focus on scalability and not on fundamental research
- Develop a data informatics platform component to encourage feedback
- Centralize access to data and informatics
- Address modularity and expandability
- Design an AMM centralized data management system with distributed teams and facilities. Use a metric for the number of center-developed materials put into products with industry defining the problem to be solved.
- Establish high throughput methodology that is long lasting and accelerates materials development and commercialization
- Address specific thrust areas in structural and high temperature applications
- Create a sustainable industry-led AMM operated by a non-profit
- Focus on specific classes of materials because addressing all materials is too broad
- Identify the critical mass to address scaling to manufacturing. It doesn't have to be single site. However, if it is too distributed, there will not be a critical mass for each location. Co-location could be a viable approach to achieve a critical mass.
- Develop an approach to obtain high quality people and tools
- Consider fast device prototyping on manufacturing relevant tools
- Locate the institute close to small businesses
- The institute's mission should be broad enough for wide applications (e.g., interfaces, surfaces)
- Create a core innovation engine/system with the common tools and data management system that is applicable to a broad range of materials. Add tools for select classes of energy materials. Create integrated product teams that focus on specific challenges for specific energy materials in TRL/MRL 4 to 7.
- Consider shared resources such as tools, expertise, modeling, and manufacturing relevant tools and processes. Solve specific application/product driven problems, rather than conduct "generic studies." The tools and capabilities are the "pre competition" part. The specific projects may be proprietary so IP management is critical for deep industry involvement.

What will be the revenue stream?

- The successes will be the spinoffs themselves. Focusing only on revenue will not lead to success.
- Industrial partners bring the problems. An institute brings the solution.

Management Needs to be Centralized

- Determine how management will be centralized within the center

Table 5. Summary of Participants' Ideas and Comments Related to an AMM Centralized Institute and/or Distributed Consortium

How does this compare with other MGI/ICME based programs?

- Create a Materials Taskforce for solving problems and acting as a bridge to other consortia
- Use a Materials Taskforce to assist others
- Develop a plan for a self-sustaining system
- Develop a combinatorial toolset for soft materials and composites. A processing-characterization Institute should bridge material and processing gaps between other institutes to enable new material and products.
- Develop a core for data management with spokes and distributed capabilities.

Importance of interfaces and surfaces for developing new devices?

- Process relevance is just as important as capturing materials. Address the importance of new requirements for manufacturing processes that may have additional needs to deal with interfaces and surfaces of new materials to be incorporated into new devices, e.g. production of flexible electronic devices using nanotechnology.

Other Suggestions for an NNMI Institute

- No relevant comments were given in this category

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5. HIGH-EFFICIENCY MODULAR CHEMICAL PROCESSES/PROCESS INTENSIFICATION (HEMCP/PI)

Introduction

Process Intensification (PI) targets dramatic improvements in manufacturing and processing by rethinking existing operations into schemes that are both more precise and efficient than the existing operations. PI improvements frequently involve combining separate unit operations such as synthesis and separation into a single piece of equipment resulting in safer, cleaner, and less expensive manufacturing. At the molecular level, PI technologies significantly improve mixing. In turn this improves mass and heat transfer properties, reaction kinetics, yields, and the specificity in the molecular structure of the resulting reaction product confirmation. Taken together these improvements translate into reduced equipment size and process complexity further lowering cost and risk in manufacturing facilities.

The current conventional improvement paradigm for continuous process technology relies on economies of scale to achieve efficient and economic operation. As a result to be economically competitive, chemical plants typically require huge capital expenditures and the associated high degree of capital risk. All of this makes the adoption of new technology extremely risky often stifling innovation. Moreover, such centralized processes are ill-suited for adapting to rapidly changing market demands and cannot be re-deployed closer to new resources or markets.

The 'bigger is better' conventional PI improvement paradigm can be reversed with the development of chemical process modules. By using modules, chemical processes become more efficient. High-efficiency modules takes chemical processing from large-scale, fixed asset chemical plants to small-scale, high-efficiency, deployable, plug-and-play reactors and separation equipment that can leverage existing manufacturing capabilities, and, deploy innovative technology and environmentally friendly improvements.

Working concept and white papers were developed on PI as a basis for specific topics areas of interest included in a Request for Information (RFI) titled Specific Clean Energy Manufacturing Focus Areas Suitable for a Manufacturing Innovation Institute, DE-FOA-0001158, released on August 29, 2014[1]. These papers were internal Technical Team working documents and remain in draft.

Focused discussion questions were prepared in advance to capture feedback on potential objectives that included the

1. Design of industrial scale 'plug-and-play' modular continuous-process technology for commercial applications, capable of widespread implementation throughout the U.S. industrial sector
2. Creation of a backbone platform for modular continuous processes that support the validation of new/enhanced reactor and separation technologies, new automation technology, and components fabricated through advanced manufacturing techniques, and

[1] Department of Energy, Request for Information, "Specific Clean Energy Manufacturing Focus Areas Suitable for a Manufacturing Innovation Institute, DE-FOA-0001158, August 29, 2014. https://eere-exchange.energy.gov/#FoaIdd682ac7b-02d0-4c10-a424-7c00da3775a4

3. Open-source design methodologies and guidelines for modular, container-based production units that apply process intensification concepts and innovative decision tools.

In addition participants were asked to comment on cross-cutting and specific manufacturing challenges, and the basic rationale and justification for a manufacturing innovation institute focused on HEMCP/PI, consistent with the mission of DOE.

Feasibility for HEMCP/PI Activity

Question 1: In your mind, is achieving high efficiency at small-scale "plug and play" type operations feasible? If so, what manufacturing operations/processes stand to benefit from this technology development?

Table 1 summarizes participants' comments on both broad and specific manufacturing operations that could be applicable to a PI activity. If PI is currently in use, it was noted by the participants.

Table 1. Participants' Comments Relating to Manufacturing Operations that are Applicable to HEMCP

- Multi-functional reactor or modular process equipment with pre-defined interface to utilities
- Hybrid processes using alternative energy, e.g. solar, wind
- Hybrid processes using biotechnology with catalysis
- Methane to non-syngas route for fuel production, e.g. methane to ethylene
- Small reactors for use by small businesses
- Novel approaches to chemical reactions different from conventional chemical engineering approaches
- Modules to perform each unit operation
- Reactors that operate at peak efficiency over different production ranges
- Natural applications of distributed processing, i.e., flare gas conversions to chemicals, liquids, and fuels
- Processes where transport costs of raw materials are more than the cost of the process itself
- Methane conversion processes near the source/feedstocks
- Well-head natural gas conversion
- "Plug and play" operations consistent with a new process control paradigm
- Basic chemical production via syngas methods that use combined operations (e.g., reactions/separations) and that are flexible enough for modular design
- Applicable to low yield reactions
- Very selective on-demand products
- Scalable gas clean up and conditioning
- Processes requiring precise control of transport properties
- Reactions that need close heat transfer (endo- and exothermic), e.g. Fischer–Tropsch processes
- Various conversion/separation processes
- Membrane reactors for equilibrium-limited reactions
- Radiochemical processing
- Similar to agile value chains (ASCPM) with pharmaceuticals
- Transport of electrons in addition to heat and chemicals
- Modular reactors utilizing dispersed waste or otherwise under-used feedstocks to chemicals
- Metals extraction, e.g., aluminum and magnesium extraction performed by PI-like methodologies is being evaluated now in pilot/lab scales
- Methane to syngas in modular reactors

Value Proposition

QUESTION 2: What is the value proposition of modular small-scale chemical reactors in the grand scheme of manufacturing processes?

Table 2 summarizes participants' comments on the economic payback and technical improvement that could be realized if PI activity is successful.

Table 2. Participant's Comments Relating to Value Proposition of PI vs. Traditional Chemical Processes
Economic Benefits from Realizing PI
• Limits capital expenditure and business risk per unit produced and scaled up; if applicable could lead to more financing options and faster payback • Reduces the power consumption needs of auxiliary equipment • Reduces R&D costs by allowing for multiple field tests of TRL 4-7 technologies to further reduce overall risk • Opens up export markets for production equipment • Develops standardized plug and play systems, common heat exchangers, power, and controls • Substitutes dynamic market drive for technology push (value chain) • Leads to easy mobility of modular reactors, e.g., ease of transportation • Improves security by minimizing reliance on centralized systems • Leverages existing manufacturing if the components are already mass manufactured • Creates low economic barrier to entering/initiating new markets • Makes scale-up cost more manageable • Drives market growth and flexibility, without significant cost impact • Improves brand interests
Manufacturing Impacts from Realizing PI

• Shortens manufacturing learning cycle and knowledge collection
• Allows for faster technological change and adaptation
• Allows for feedstock use at point of production
• Enables better control of operating conditions, e.g., temperature, pressure, residence time
• Introduces small modular systems for future enhancements or new disruptive processes
• Scales down processes quickly
• Introduces new reactor technology more quickly
• Improves all-round manufacturing performance, e.g., increase product load per unit power and cost
• Shifts/adjusts supply chains and distribution quickly
• Speeds use of high efficiency technology
• Enables flexible, automated small footprint, low cost, and quick setup production (small feedstock operations)
• Enables use of feedstocks that are "waste," e.g., use low-value products to make chemicals and/or fuels that would otherwise be landfilled
• Supports higher conversion and energy efficiency, lower operating costs, shorter time to market (faster scale-up and commercialization)
• Right-sizes the modular reactor:
  – Reduces manufacturing and custom engineering and setup costs on site
  – Standardizes transportation methods
  – Enables mass manufacturing

Other Benefits
• Enables innovation, investment, and product flexibility • Creates value for new processes

Table 2. Participant's Comments Relating to Value Proposition of PI vs. Traditional Chemical Processes

- Allows for climate adaptation
- Reduces fuel usage and GHG emissions; therefore, lowers the costs and environment impact
- Spurs complementary and supplementary technologies and technologies, e.g., advanced sensing
  - Creates links to Advanced Sensing, Control and Platforms for Manufacturing (ASCPM) value chain and the modularity already in ASCPM

Unique Deliverables of a CEMI Institute

QUESTION 3: What can be uniquely accomplished by creating a platform for small-scale modular reactors through a Clean Energy Manufacturing Innovation Institute that cannot be achieved through the existing partnership approach to funding solicitation?

Table 3 presents participants' ideas for the advantages gained by performing PI R&D under the auspices of an institute rather than a traditional funding mechanism.

Table 3. Participants' Comments Relating to Potential Unique Deliverables of a PI Institute
Technical
• Creates a database for property measurements and characterization: precompetitive and proprietary • Collects and makes available models and data • Creates multidisciplinary competencies, e.g., reactor design, control/automation, data analytics, standards, risk, process modeling • Realizes appliance-level reactor for domestic fuel production from gas or solar energy at home • Produces uniform standards and open access to information • Creates efforts on standardization, demonstration, and computation • Develops new technical/manufacturing tools based on input from many institute participants • Drives success by base lining industry needs/issues/challenges
Other
• Creates PI institute designed to – Scale with size and scope of work – Integrate a variety of partners – Create funding opportunities on diverse interests/needs • Creates intellectual synergy between universities, industry, and government that lead to collaborative approaches by design • Enables a large effort with stakeholder involvement for a sustained 5-7 years or longer • Demonstrates and accelerates a holistic new business/technology mindset • Educates and trains skilled and semi-skilled workforce • Stimulates creation of a supply chain for equipment manufacturing • Works across more interdisciplinary lines (broad scope) on critical problems • Creates a PI institute that allows multiple stakeholders to have a systematic view of institute opportunities • Drives regulatory standardization • Creates an expertise and problem solving skillset reservoir for small and medium-size businesses who cannot afford R&D • Avoids the one product-solution by reaching across silos • Creates more opportunities/visibility to transfer technology and knowledge • Establishes multiple opportunities throughout the institute's lifetime for different technologies and entities to contribute and participate in the technology development • Provides a collaborative environment and sustained focus over multiple years • Improves collaboration and successes by bringing together many vantage points • Creates ground rules for intellectual property protection derived from focused efforts • Interacts/collaborates with other institutes around the world in this field • Allows U.S. chemical engineers to look at processes/reactions that are not being looked at now nationally or internationally • Acts as representation of the consumer market • Changes the fundamentals of how intermediates and chemicals are transported and impact many manufacturing businesses and revenue models

Focus Areas for a Potential PI Institute

QUESTION 4: If the HEMCP/PI institute is established, what technology development challenges, key skillsets (machine design, process modelling, etc.), equipment, tools, capabilities, other topical areas, etc. should it focus its attention on?

Table 4 lists participants' ideas on those topics areas that a DOE-AMO PI institute should focus on to realize the objectives of this activity.

Table 4. Participants' Comments Related to Potential Focus Areas for a PI Institute
Technical

- Design and testing of reactors design, i.e., reactor modeling
- Define grand challenges for modular manufacturing (3-4 which are common to most processes)
- Develop a scalable unit operation
- Develop "modular skill sets" for HEMCP/PI
  - Process simulations techno-economic development
  - Life cycle, regeneration, and recycling considerations
  - Infrastructure for piloting, e.g., National Carbon Capture Center (NCCC)
- Focus in the
  - Near term (econ/energy)
    - Physical modeling
    - Retrofit modeling
    - Line operation
    - Microgrids
    - Inventory (storage)
  - Longer term (ecosystem)
    - Value chain flexibility
    - Modularization technologies
    - Polymerization
    - Gas liquefaction
    - Ethane to ethylene in a ceramic membrane
    - Ethane to ethylene in a membrane reactor
    - Ammonia – simplify separation to have zero ammonia to recycle
    - Ammonia production – reaction between atoms and/or ions instead of molecules H^+ instead of H_2 x
- Develop unique tools for property measurements
- Invest in novel modular reactor designs and reaction engineering technology validation library of processes
- Perform construction material analysis for modular systems since their lifetimes are order of magnitude less than traditional plants
- Technology and materials to reduce cost of producing micro-channel heat exchange reactors (PI modules)
- Develop systems integration tool box to support grantees

Table 4. Participants' Comments Related to Potential Focus Areas for a PI Institute

Manufacturing

- Promote standardized practices for manufacturing, data use, and best practices
- Determine relationships between life cycle energy and cost savings
- Bring equipment cost down cost – volume curve; demonstrate value of mass manufacture
- Devote attention to mild condition and lower temperature and pressure processing (catalysis, hybrid processing)
- Develop new manufacturing techniques for new requirements
- Focus more on developing resources, standards, regulations rather than technical design
- Continue to advance plant safety technologies
- Advance skills development for process control, remote sensing, and monitoring
- Devote some resources to on-going process improvements being made in conventional systems
- Establish a shipping container manufacturing certification
- Focus on need for process controls, e.g., associated sensing, models/data, and appropriate time scales

Education

- Establish institute public education and idea promoting campaign
- Drive changes in chemical engineering curricula to train engineers in the PI paradigm, e.g., T.U. Delft course
- Educate field maintenance personnel with standard processing knowledge and tool usage
- Re-invigorate study and interest in old mature industry
- Promote innovation in an industry that has fallen behind in "chemical and process" intensification

Other

- Use techno-economic assessments to identify impactful opportunities impacting energy, emissions, capital expenditures
- Analyze the growth opportunities
- Categorize and identify TRL 4-7 gaps, identify common needs, assess the value of the gaps, prioritize as much as possible

Ensuring Industry Commitment

QUESTION 5: **How can industry engagement be insured for long-term industry involvement and institute success?**

Table 5 captures participants' input on the kinds of concepts and assurances that industry needs to ensure a long term relationship with a DOE Institute focused on PI.

Table 5. Participants' Comments Relating to Industry Commitment
• Establish a value proposition not based on cost (demonstration, trust) • Establish long term investment • Design institute simply making progress easy to measure • Provide consultations, e.g., through the Manufacturing Extension Partnership (MEP) • Develop climate response solutions, e.g., CHP • Focus on precompetitive products and technologies • Develop the fundamentals of significance to the practice • Conduct risk and reliability life-cycle cost analysis • Establish the opportunities for 'quick wins' with low hanging fruit • Make the institute industry driven • Demonstrate that solutions are meeting industries' needs • Balance the staffing with industry personnel and subject matter experts • Focus on breaking down the barriers of implementation and not process specific designs • Address fundamental concerns, e.g., fouling, corrosion, durability, control and integration • Evaluate pre-patented materials and processes • Make tool and pilot development a part of the institute focus • Make computational techno-economic models a part of the institute focus • Clearly layout a value proposition with the following factors in mind • Cost – Sales – Permitting – Fear – Intellectual property (IP) – Competition – Regulation – Markets – Products • Make IP retention attractive • Make the contracting process simpler • Focus on developing trust • Make tools, lifecycle analysis (LCA), and measurement a part of the institute focus

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6. MODERN FIBERS AND TEXTILES

Introduction

Historically, U.S. dominance in textiles was spawned by manufacturing innovations. A similar class of innovations made in the context of next-generation fibers and smart multi-functional textile matrices will precipitate an industry response not unlike the last one. Textiles are vital for uniforms, protective and load-bearing equipment (ballistic/stab puncture/-environmental/physical trauma mitigation), personnel and cargo aerial precision delivery systems, novel structures for turbine and rotor hubs, protective shelters, primary and secondary airframe sectors, energy harvesting equipment, and a variety of other smart textile (integrated electronics) products that keep our service members protected, unburdened and empowered across the spectrum of operations, spanning conflict to peacekeeping. Maintaining the highest level of survivability, sustainability, mobility, combat effectiveness, and field quality of life for U.S. armed forces and homeland defenders is critical to our nation's security. Currently, the U.S. textile industry is in need of leap-ahead manufacturing capabilities to surpass global markets. The textile DoD market segment has demonstrated efficiencies with the private sector pertaining to automotive, aerospace, energy, sporting/adventure apparel, equipment, and medical applications. Recent textile technological advancements in academia and laboratory settings have realized multifunctional and intelligent demonstrators with limited product to market. Cost, scale-up challenges, and lack of prioritized design features, have drastically changed the available pool of incremental and disruptive technologies that the industry can harvest and place into production.

A concept paper and a white paper were developed as a basis for specific topic areas of interest to be included in a Request for Information (RFI) titled Institutes For Manufacturing Innovation, RFI-RQKM-2014-0022, released on May 22, 2014.

However, there remained a need to further engage the public and private sector for input in identifying advanced fiber and textiles manufacturing technology areas that might critically benefit from support in an organized manufacturing innovation institute and to assess the potential of such an institute on domestically competitive advanced manufacturing. The purpose of the fiber and textiles breakout session was to identify New / Modern Manufacturing Technologies, Technical Textiles and Advanced Technologies, Composite Substrates, and Potential Opportunities for an Institute.

The Fiber and Textiles breakout session focused on four key areas:

- New / Modern Manufacturing Technologies
- Technical Textiles and Advanced Technologies
- Composite Substrates
- Potential Opportunities for an Institute

Focused discussion questions were prepared in advance. Individual participant's views and responses were captured using a compression planning and brainstorming process which draws on small groups to identify and/or analyze information in a compressed time period using the focus questions and story boards for a real-time capture of ideas.

New / Modern Manufacturing Technologies

Focus Question 1: What are the research and development needs?

Table 1 summarizes participants' opinions on the research and development needs, for new and modern manufacturing technologies for fibers and textiles.

Table 1. Summary of Participants' Comments Related to New / Modern Manufacturing Technologies Research and Development Needs
Modeling
• Open source and standard simulation systems • Simulations to address design problems • Simulations to address materials property vs. process
Strategy – Guiding Principles
• Develop roadmaps for each application • Identify overlap of area of interest with other technologies, such as R2R, etc. • Update roadmaps on related technologies (R2R, fiber, textile, etc) and identify intersections • Keep an open mind for disruptive inventions
Fiber
• Identify R&D needs and advanced uses of cotton and/or cellulose • Identify performance metrics and objectives for material properties, e.g., retardant.
Guiding principles
• Innovations need to fit existing infrastructure • Need value add on raw materials transformation to products • Mitigate cost barriers • Identify standards and metrics • Determine if domestic industries show an interest in joining an institute? • Conduct a SWOT/gap analysis • Determine current value chain and throttle points for time compression

Focus Question 2*:* What are markets and supply chain opportunities?

Table 2 summarizes participants' opinions on a number of markets and supply chain opportunities for new and modern manufacturing fibers and textiles technologies.

Table 2. Summary of Participants' Comments Related to New / Modern Manufacturing Technologies Markets and Supply Chain Opportunities
Supply Chain
• Infrastructure compatibility • Raw material availability • Acceleration of quality, life time, standards development • Accurate assessment of imports (North American Industry Classification System (NAICS) / Standard Industrial Classification (SIC) Codes) • State of the art knowledge dissemination • Challenge of vertically integrated supply chain • Markets -Automotive and aerospace: light weight composites
Market Focus Area
• Market likely limited to only high-value products (e.g., wearable displays) • Manufacturing prototyping • Testing (not just make and break)

Focus Question 3*:* What are the facility needs?

Table 3 summarizes participants' opinions on a number facility needs for new and modern manufacturing Fibers and Textiles technologies.

Table 3. Summary of Participants' Comments Related to New / Modern Manufacturing Technologies Facility Needs
Facility Needs
• Understand the user base • Need space and equipment for processing to pursue R&D advancements • Standardize analytical capabilities, SIMS, etc. • Standardize machines and standards—facilities can focus on that • Are the facilities and equipment generic enough so that an institute could provide a broad prototyping capability? • Focus on small businesses • Minimize waste, emissions abatement • Gas vs. electric? • Analytics for user testing • Pilot facilities • Concentrate on a single market segment

Focus Question 4: Is there a business case for an institute?

Table 4 summarizes participants' opinions on the business case for a NNMI Institute for new and modern manufacturing fibers and textiles technologies.

Table 4. Summary of Participants' Comments Related to Business Case for a NNMI Institute
Business Needs
• Low value goods do not produce sufficient market pull for R&D • Is this topic unique enough for a NNMI Institute? • Make sure this institute does not duplicate the ongoing work on nano-engineering, advanced composites, and advanced materials • Focus the institute on customer demand signals or industry inflection points • Focus on "sleeper" applications

Technical Textiles and Advanced Technologies

Focus Question 5: What are the research and development needs?

Table 5 summarizes participants' opinions on a number of research and development needs for technical textiles and advanced technologies.

Table 5. Summary of Participants' Comments Related to Fibers and Textiles Technical and Advanced Technologies
Tech Textiles and Advanced Tech. R&D
• Develop stimuli responsive fibers • Develop thermal energy capture materials • Develop kinetic energy capture materials • Phase Change Material (PCM)-based fiber • Develop bio-energy applications • Develop bio-energy protection

Focus Question 6: What are markets and supply chain opportunities?

Table 6 summarizes participants' opinions on a number of markets and supply chain opportunities for new and modern manufacturing Fibers and Textiles technologies.

Table 6. Summary of Participants' Comments Related to Markets and Supply Chain Opportunities for Fibers and Textile Advanced Technologies
Supply Chain
• Identify value added products • Identify areas that offer significant market potential – could supply markets overseas • Establish ecosystem conduits for the supply chain (e.g., cheap transportation) • Identify the structural barriers to the U.S. supply chain (tax, transportation, regulation, energy costs, labor cost, intellectual property) • Identify and track supply chain redundancy (foreign vs. domestic) • Expedite qualification and certification (currently it takes 20 years) • Identify the supply chain – Does a supply chain even exist?
Market
• Identify opportunities for high-volume fashion and emergency response like fire fighters, police, medical • Identify various recycling opportunities (e.g., insulation, furniture) • Conduct life cycle analysis of products • Educate consumers about new textiles • Establish a new industry base for advanced textiles/technologies, including building new facilities and manufacturing setup • Target technical textile markets like medical, structural, and military • Reduce supply chain redundancy and increase suppliers where needed

Focus Question 7*:* What are the facility needs?

Table 7 summarizes participants' opinion on the facility needs.

Table 7. Summary of Participants' Comments Related to Facility Needs
Facility Needs
• The facility needs, as related to technical textiles and advanced technologies for Fibers and Textile, are identical to that for New / Modern Manufacturing Technologies.

Focus Question 8: Is there a business case for a NNMI Institute

Table 8 summarizes participants' opinions on the business case for a NNMI Institute as related to New / Modern Manufacturing Technologies.

Table 8. Summary of Participants' Comments Related to Business Case for a NNMI Institute
Business Needs
• Quality, reliability issues exist, especially for electronics/textiles, low cost markets • Focus on a single market sector • Active vs. passive fiber • Determine why funding and support for the national textiles center declined, and whether that bears on the business case for a textiles NNMI Institute • Understand the international markets and redundancy

Composite Substrates

Focus Question 9: What are the research and development needs?

Table 9 summarizes participants' opinions on a number of research and development needs, as related to Composite Substrates.

Table 9. Summary of Participants' Comments Related to Composite Substrates Technology Research and Development Needs
R&D Needs
• Functional based research • Interface related research • Material research • Properties of composite(s) in bulk production – need analysis models

Focus Question 10: What are markets and supply chain opportunities?

Table 10 summarizes participants' opinions on a number of Composite Substrates markets and supply chain opportunities.

Table 10. Summary of Participants' Comments Related to Composite Substrates Markets and Supply Chain Opportunities
Opportunities
• Specific supply chains for composite substrates are still evolving but there are existing domestic supply chains that can be strengthened, e.g., Boeing's supply chain • Niche supply chains that are vertically integrated and but unique • Refine application overlap with AMM • Create a roadmap to define the market

Focus Question 11: What are the facility needs?

Table 11 summarizes participants' opinions on a number facility needs for Composite Substrates.

Table 11. Summary of Participants' Comments Related to New / Modern Manufacturing Technologies Facility Needs
Facility Needs
• Similar to New / Modern Manufacturing Technologies and Technical Textiles and Advanced Technologies • Collaborate with other institutes and laboratories • Use a hub and spoke model • Look for core needs that are in common across applications • Identify the application first

Focus Question 12: Is there a business case for a NNMI Institute?

Table 12 summarizes participants' opinions on the business case for a Composite Substrates Institute.

Table 12. Summary of Participants' Comments Related to Business Case for a NNMI Institute
Business Needs
• Non duplicative business case • Market and business case are related. In the short-term, the market for composite systems is niche. • Does an industry back the composites institute or the textile or both? • Markets may be too niche/small to justify an institute • Focus on fiber manufacturing

Potential Opportunities for an Institute

Focus Question 13: Which areas have the maximum market pull?

Table 13 summarizes participants' opinions on areas of maximum pull for a new Fibers and Textiles institute.

Table 13. Summary of Participants' Comments Related to the Areas of Maximum Market Pull for a NNMI Institute
Areas of Maximum Market Pull
• Handling and building of large composite components, e.g. wind turbine blade • Other markets like large ceramics and oil and gas as applications • Identify non-aerospace needs. (Market pull cannot be driven by a single industry.)

Focus Question 14: What are potential opportunities for an institute?

Table 14 summarizes participants' opinions on the potential opportunities for a Fibers and Textiles institute.

Table 14. Summary of Participants' Comments Related to the Potential Opportunities for a Fibers and Textiles NNMI Institute
Roles
• Enhance the quality and reliability of fibers and textiles • Consider dividing applications into two areas: those which require qualified compliance and those that do not • Invest in concurrent projects at TRL 3-5 and 5-6+ to connect the new science with new applications • Promulgate workforce development. Conduct regional assessments of what is available and needed including the expected turnover
Model
• Establish a hub and spoke model • Play "matchmaker" by connecting tier 3 suppliers to tier 2 suppliers
Market Focus
• Need to address the needs of non-traditional industries like power generation and oil and gas

Contributors

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APPENDIX

Agenda

Agenda for Multi-Topic Workshop

Fort Worth, TX | October 8-9, 2014

Day 1	
Time	**Activity**
8:00 am	Registration
8:30	Welcome by *Mark Johnson, Director, DOE Advanced Manufacturing Office*
8:40	DoD Remarks: *Adele Ratcliff, DoD/OSD Manufacturing Technology Office*
9:10	DOE Remarks: *Mark Johnson, Director, DOE Advanced Manufacturing Office*
9:40	Instructions
9:50	Break
10:20	**Topic Area Sessions**
	● Engineered Nanomaterials ● Advanced Sensing, Control, and Platforms for Manufacturing (ASCPM) ● High Value Roll-to-Roll Processes (R2R)
12:00 pm	Lunch
1:00	Resume sessions
4:00	Break
4:30	**Comments from Sessions**
4:30	● Engineered Nanomaterials
4:45	● ASCPM
5:00	● R2R
5:15	Adjourn

Day 2	
Time	**Activity**
8:00 am	Assemble
8:15	Review Instructions
8:30	**Topic Area Sessions** ● Advanced Materials Manufacturing (AMM) ● High-Efficiency Modular Chemical Processes (HEMCP) ● Modern Fiber and Textiles
12:00 pm	Lunch
1:00	Resume sessions
2:00	**Comments from Sessions**
2:00	● AMM
2:15	● HEMCP
2:30	● Modern Fiber and Textiles
2:45	Closing comments
3:00	Adjourn

Participants of Workshop

Name	Company
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George Zhang	ABB Corporate Research Center
Liang Zhang	University of Connecticut
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Weidong Zhou	University of Texas at Arlington

Acronym List

2D	two-dimensional
ALD	atomic layer deposition
AMM	Advanced Materials Manufacturing
AMO	Advanced Manufacturing Office
ARALL	Aluminum-Lithium, aramid aluminum laminate
ARPA-E	Advanced Research Program Agency-Energy
ARDEC	Armament Research, Development and Engineering Center
ASCPM	Advanced Sensing, Control and Platforms for Manufacturing
BEETIT	Building Energy Efficiency through Innovative Thermodevices
BIPV	building integrated photovoltaic
CCEFP	Center for Compact and Efficient Fluid Power
CEMI	Clean Energy Manufacturing Initiative
CV	Coefficient of variation
DCS	digital control system
DFT	design for testability
DMS&T	Defense-Wide Manufacturing Science and Technology
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DSC/TGA	differential scanning calorimetry/ thermo-gravimetric analysis
EERE	Office of Energy Efficiency and Renewable Energy
FE	finite element
FHE	Flexible Hybrid Electronics
GHG	greenhouse gas emissions
HEMCP	High-Efficiency Modular Chemical Processes
HEMCP/PI	High-Efficiency Modular Chemical Processes/Process Intensification
HPC	high performance computing
HTE	high-throughput experimentation
HV	high value
HVAC	heating, ventilation and air conditioning
ICME	integrated computational materials engineering
IP	intellectual property
IT	information technology
JCAP	Joint Center for Artificial Photosynthesis
LBNL	Lawrence Berkeley National Laboratory
LCA	lifecycle analysis
LEDs	light emitting diodes
LGGE	low greenhouse gas emissions
ManTech	Manufacturing Technology Office
MDF	manufacturing design facility
MEMS	micro-electro-mechanical systems
MEP	Manufacturing Extension Partnership

MGI	Materials Genome Initiative
MIBP	Manufacturing and Industrial Base Policy
MRL	Manufacturing Readiness Level
MTF	meantime to failures
NAICS/SIC	North American Industry Classification System / Standard Industrial Classification
NCCC	National Carbon Capture Center
NCMC	Technology Combinatorial Methods Center
NIST	National Institute of Standards and Technology
NNI	National Nanotechnology Initiative
NNMI	National Network for Manufacturing Innovation
NREL	National Renewable Energy Laboratory
NS	Nanostructures
NSF	National Science Foundation
NTSC	National Science and Technology Council
ODS	ozone depleting substances
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
PCM	Phase Change Material
PEMs	proton exchange membranes
PPP	Public Private Partnership
PV	photovoltaic
R&D	research and development
R2R	Roll-to-Roll
RAM	random access memory
RD&D	research, development and demonstration
RFI	Request for Information
ROI	return on investment
SEMATECH	semiconductor manufacturing technology
SLAC	Stanford Linear Accelerator Center
TCM	theoretical and computational modeling
TCO	transparent conductive oxide
TRL	Technology Readiness Level
USAF	U.S. Air Force
VTO	Vehicle Technologies Office

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Office of the
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