American Energy & Manufacturing Competitiveness Partnership

Accelerating Advanced Materials Manufacturing

Executive Summary

On May 8, 2015 the Council on Competitiveness (Council), the U.S. Department of Energy Offices of Fossil Energy (FE) and Energy Efficiency and Renewable Energy (EERE), the National Energy Technology Laboratory (NETL), and Oregon State University will co-host the sixth American Energy & Manufacturing Competitiveness (AEMC) Partnership dialogue – the first of a series focused on accelerating advanced materials manufacturing. This dialogue continues from a progressive dialogue series convened as part of the AEMC Partnership – a three-year effort between the Council and EERE to bolster American competitiveness through advanced clean energy manufacturing and increased energy productivity, and to address the dynamic changes affecting the national and global energy landscape.

During the 2013 and 2014 activities of the AEMC Partnership – spanning 5 dialogues and 2 annual AEMC Summits to date – national leaders from across industry, academia, labor, national laboratories, and other critical stakeholders have consistently emphasized the importance of developing, manufacturing, and deploying advanced materials as a critical leverage point with the potential to unleash a U.S. manufacturing renaissance by creating the conditions in this country to promote the adoption of clean energy technologies, and deeper investment in energy technology manufacturing. This sixth dialogue advances the conversation from the earlier and broader discussions around bridging individual organizations in the innovation ecosystem and the benefits of public-private partnerships – to focus attention on the critical leverage point and cross-cutting potential of advanced materials.

The Council and FE are launching a targeted series of discussions in 2015 – spanning the United States from Portland, Oregon, to Chicago, Illinois, to College Station, Texas for the sixth, seventh, and eighth dialogues of the AEMC Partnership – around accelerating the development, deployment, and diffusion of advanced materials into the manufactured marketplace and the wider economy. AEMC Partnership Dialogue 6 gathers leaders from industry, academia, non-profit organizations, and the national laboratory system to discuss specific barriers and opportunities in developing, manufacturing, and deploying advanced materials to increase U.S. clean energy manufacturing competitiveness.

AEMC Partnership Dialogue 6 is another step in the ongoing conversation around increased U.S. energy, manufacturing, and economic competitiveness, and leads into the upcoming 2015 AEMC Summit that will take place in Washington, D.C. on September 16th.

The American Energy and Manufacturing Competitiveness (AEMC) Partnership Overview

The AEMC Partnership is a 3-year effort by the Council and EERE to bring together national leaders to address a rapidly shifting energy and manufacturing landscape. In a series of progressive dialogues since 2013, participants have considered actions that can be taken now to bolster American competitiveness in these areas. This is an effort formed under the DOE Clean Energy Manufacturing Initiative - a strategic integration of and commitment to manufacturing efforts focusing on American competitiveness in clean energy manufacturing. The goals of the CEMI and AEMC Partnership are to:

- Increase U.S. competitiveness in the production of clean energy products: Strategically investing in technologies that leverage American competitive advantages and overcome competitive disadvantages and
- Increase U.S. manufacturing competitiveness across the board by increasing energy productivity: Strategically investing in technologies and practices to enable U.S. manufacturers to increase their competitiveness through energy efficiency, combined heat and power, and taking advantage of low-cost, domestic energy sources.

The AEMC Partnership is broadly divided into two phases, “mapping the landscape” and the AEMC Partnership progressive dialogue series.

Phase One: Mapping the Landscape

To cultivate topics for the progressive dialogue series, and to provide a foundation for the larger goals of the AEMC Partnership, the Council performed an extensive literature review and mapped 184 past and current research efforts across the United States and around the globe concerning three core topics:

- Linkages between manufacturer efforts in energy efficiency and renewable energy and manufacturing competitiveness;
- Energy-related barriers to manufacturing competitiveness; and
- Models for PPPs for fostering competitive industries.

The literature review is documented in the Council publication, *The Power of Partnerships*, and its companion piece, *A Summary of Public-Private Partnerships.*[1]

[1] These documents are available at http://www.compete.org/about-us/initiatives/aemcp/.

Phase Two: The AEMC Partnership Progressive Dialogue Series

The second phase of the AEMC Partnership includes a total of five progressive dialogues in 2013 and 2014, leading into AEMC Partnership *Materials Manufacturing Accelerator* Dialogue 1, in which participants generate new insights pertaining to the overall goals of the AEMC Partnership, as well as inform the creation of a public-private partnership concept to further advance the initiative's goals.

Reviewing Previous AEMC Partnership Dialogues

Inaugural Dialogue: Launch

The inaugural dialogue in Washington, D.C. on April 11-12, 2013, hosted by Mr. James Clifton, Chairman and CEO of Gallup, Inc., laid out the objectives of the AEMC Partnership, and began the process of closely examining a range of PPP model types and technology areas, drawing on the real-world experience, insights, and knowledge of leaders and practitioners from across a range of stakeholders— including government, industry, academia, labor and the national laboratories.

The Honorable David T. Danielson, Assistant Secretary for Energy Efficiency and Renewable Energy, U.S. Department of Energy; the Honorable Deborah L. Wince-Smith, President & CEO, Council on Competitiveness; Mr. Jason Miller, Special Assistant to the President for Manufacturing Policy, National Economic Council; Ms. Elizabeth Wayman, Director, Clean Energy Manufacturing Initiative, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy; and Mr. Chad Evans, Executive Vice President, Council on Competitiveness

Dialogue 2: Bridge

President Lloyd Jacobs of the University of Toledo hosted the second dialogue on June 20th, continuing the discussions sparked during the inaugural dialogue. This dialogue focused on Toledo as a case-study for successful informal and formal partnerships that can drive regional manufacturing transformation, in this case by leveraging materials science and engineering.

Dr. Jay Kim, Director, School of Dynamic Systems, University of Cincinnati; Mr. Lorry Wagner, President, Lake Erie Energy Development Corporation; the Honorable Deborah L. Wince- Smith, President & CEO, Council on Competitiveness; Dr. Lloyd A. Jacobs, President, The University of Toledo; and the Honorable David T. Danielson, Assistant Secretary of Energy Efficiency and Renewable Energy, U.S. Department of Energy

Dialogue 3: Evaluate

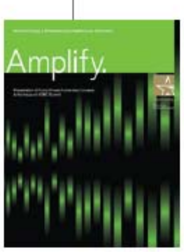
Dr. Mark Little, Senior Vice President and Chief Technology Officer of GE and Director of the GE Global Research Center at the GE Global Research Center in Niskayuna, New York, hosted the third dialogue at the GE Global Research Center in Niskayuna, New York. The Council and EERE presented five specific PPP concepts for dialogue participants to discuss and critique around the major themes of leveraging national laboratories for manufacturing competitiveness, facilitating the scaling of innovative technologies to mass-manufacturing in the United States, and bringing public and private sectors together to accelerate the development and deployment of advanced materials in supply chains.

NOVEMBER 2013
PPP Concept Leadership Survey
Survey and Research
Conducted by the Council on Competitiveness

APRIL 16, 2014
AEMC Partnership Dialogue 5: Detail
Co-hosted by University of California, Berkeley
Berkeley, CA

2014

DECEMBER 12, 2013
Inaugural AEMC Summit: Amplify
Washington, D.C.



SEPTEMBER 17, 2014
2014 AEMC Summit
Washington, D.C.

AEMC Partnership Dialogue 3
Niskayuna, NY

Mr. Chad Evans, Executive Vice President, Council on Competitiveness; the Honorable Paul Tonko, U.S. House of Representatives; the Honorable Deborah L. Wince-Smith, President and CEO, Council on Competitiveness; the Honorable David T. Danielson, Assistant Secretary for Energy Efficiency and Renewable Energy, U.S. Department of Energy; Ms. Elizabeth Wayman, Director, Clean Energy Manufacturing Initiative, Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy; Ms. Jetta Wong, Deputy Director, Clean Energy Manufacturing Initiative, Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy; and Dr. Mark Little, Senior Vice President and Chief Technology Officer, General Electric and Director, GE Global Research

Dialogue 4: Focus

Mr. Michael Splinter, Executive Chairman of the Board of Directors of Applied Materials, and Dr. Omkaram Nalamasu, Chief Technology Officer of Applied Materials, hosted the fourth dialogue that focused squarely on evaluating two PPP concepts and honing the attributes of a clean energy manufacturing public-private partnership:

- Lowering risk and accelerating the adoption of advanced materials in the clean energy space through materials characterization, quantification, and standards development, and
- Lowering barriers to the scaling of existing, promising prototypes in the clean energy space by placing strategic resources on both sides of the scale-up "valley of death."

MAY 8, 2015
AEMC Partnership Dialogue 6
Co-hosted by National Energy Technology Laboratory and Oregon State University
Portland, OR

JULY 24, 2015
AEMC Partnership Dialogue 8
Co-hosted by Texas A&M University
College Station, TX

NOVEMBER XX, 2015
AEMC Partnership Dialogue 9
Co-hosted by XX
Boston, MA

2015

JUNE 16, 2015
AEMC Partnership Dialogue 7
Co-hosted by Argonne National Laboratory
Chicago, IL

SEPTEMBER 16, 2015
2015 AEMC Summit
Washington, D.C.

AEMC Partnership Dialogue 4 Santa Clara, CA

Mr. Michael R. Splinter, Executive Chairman of the Board, Applied Materials, Inc. and the Honorable Deborah L. Wince-Smith, President and CEO, Council on Competitiveness

AEMC Partnership Dialogue 5 Berkeley, CA

ABOVE: The Honorable Jennifer M. Granholm, Former Governor and Distinguished Practitioner of Law and Public Policy, University of California, Berkeley and The Honorable Deborah L. Wince-Smith, President and CEO, Council on Competitiveness

BELOW: Dr. Nicholas Dirks, Chancellor, University of California, Berkeley, the Honorable David T. Danielson, Assistant Secretary for Energy Efficiency and Renewable Energy, U.S. Department of Energy, and Dr. Jon Schaeffer, Senior Engineering Manager, GE Power & Water

Dialogue 5: Strengthen

Dr. Nicholas Dirks, Chancellor of The University of California, Berkeley hosted the fifth dialogue on the university campus, where the Council and EERE presented a case-study of one tool-based PPP centered around increasing awareness and access to advanced computing resources. Discussions during the fifth dialogue supported the mutual benefit of partnerships to organizations across the ecosystem, when aligned around a need such as materials characterization or manufacturing optimization or around streamlined access to a tool, such as advanced computing resources.

Setting the Stage for AEMC Partnership Dialogue 6

Advanced materials can drive significant enhancements in products and the economy by increasing the efficiency and optimizing energy products. Moreover, material technologies have the ability to increase the competitiveness of all manufacturing sectors, for example through broadly applicable advances in heat recovery processes, lubricants that reduce wear and on process equipment, and shaping processes that reduce material waste. As such, materials science and engineering have remained a central leverage point capable of meeting the goals of the AEMC Partnership.

Building a program around accelerating the development, manufacture, and deployment of advanced materials also helps address three specific manufacturing barriers that inhibit dramatic progress in clean energy manufacturing: insufficient access to capital, technical uncertainties from technical risk and imperfect information, and insufficient access to innovation infrastructure.[2]

- **Capital Requirements:** While insufficient capital is often attributed to a dearth of new innovative energy technologies, insufficient capital also strangles the design, development, manufacture and deployment of advanced materials. The amount of investment required to design, develop, manufacture, and deploy advanced materials can shelf a project mid-stream or even inhibit a project from beginning.

- **Overcoming Technical Uncertainty & Imperfect Information**
  Market incentives encourage firms to focus on low-risk, incremental improvements to existing technologies rather than investing in new and unproven transformational technologies. Often, innovators and investors lack adequate information to make informed decisions. These high technical risks dampen the incentives to the increased creation and use of new technologies.

- **Industrial Innovation Infrastructure & Expertise:** This barrier refers to a lack of access to shared infrastructure and expertise on which industry scientists and engineers could draw to increase speed and lower costs on the path from design to production and commercialization. Typically, innovation infrastructure refers not only to shared research and testing equipment, but also to university or national laboratory personnel with specialized knowledge and skills.

To align efforts in both the public and private sectors, a national initiative to support advanced materials could be built around (1) specific classes of advanced materials, (2) specific processes for a wide variety of advanced materials, or (3) specific tools or activities useful for a wide variety of advanced materials. A selection of advanced materials and specific tools or activities is discussed in greater detail below.

A national advanced materials initiative could:

1. **Support the design, development, manufacture, and deployment of classes of advanced materials such as:**
   a. **Alloys**
   b. **Separation products**
   c. **Coatings**
   d. **Catalysts**

2. **Support the research, development, and demonstration for all materials of processes such as:**
   a. **Modeling/Design**
   b. **Synthesis**
   c. **Processing/Manufacturing**
   d. **Characterization**
   e. **Application**

3. **Support the development of and access to tools or activities for all materials such as:**
   a. **Public sector capabilities map**
   b. **Materials data repository, management, and informatics**
   c. **Increased access to tools**
   d. **High-throughput simulations and experimentation**

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[2] The Council identified and documented twenty unique manufacturing barriers in the *Power of Partnerships* during Phase One of the AEMC Partnership. During Phase Two of the AEMC Partnership**,** regional and national clean energy manufacturing stakeholders from the public and private sectors shared insights and validated this list of barriers.

Potential Classes of Advanced Materials

After gathering input from stakeholders, the Council and the Department of Energy have considered the acceleration of advanced materials into products and processes in the marketplace as a cross-cutting method to achieve the goals of the Clean Energy Manufacturing Initiative. By engaging a broad industrial community and increasing access to national innovation capabilities – including expertise and tools – advanced materials may be better designed, developed, manufactured, and deployed to both accelerate the development and commercialization of clean energy technologies and increase the energy productivity of many sectors of the economy.

Several materials classes have a great potential to cross-cut many types of technologies and sectors of the economy – in addition to improving the productivity and competitiveness of the sectors – with relevance and interest across the Department of Energy Office of Fossil Energy, Office of Energy Efficiency and Renewable Energy, and Office of Nuclear Energy, including next generation alloys, separation materials such as sorbents and membranes, catalysts, and coatings which are discussed briefly below.[3]

Alloys

The desire for superior characteristics in metals has driven research in a continuous quest to find alloys that are stronger, more ductile, formable, corrosion resistant, high melting temperatures, yet capable of being joined, coated, and manufactured at low cost.

Figure 1: Extrusion of Inconel 740H Pipe at Wyman Gordon plant
Source: Shingledecker, J. et al. 2013

Inconel is an example of an alloy under investigation with funding from the Department of Energy for use in advanced ultra-supercritical steam boilers (at temperatures up to 760 degrees Celsius and pressures up to 5500 pounds per square inch) which will allow for the generation of electricity from coal-fired power plants at higher efficiency.[4] Materials such as Inconel have additional applicability for high temperature, high pressure piping in gas fired carbon dioxide Brayton cycles for carbon capture and solar powered carbon dioxide Brayton cycles.[5] By better understanding microstructural factors, steam-side oxidation resistance, and other characteristics that can help predict the life of alloys, a national initiative supporting further work in alloys could help

[3] This initiative will also collaborate with and integrate efforts from The Materials Project (www.materialsproject.org) and the National Network of Manufacturing Innovation Institutes.

[4] Viswanathan, R. *et. al.* U.S. Program on Materials Technology for USC Power Plants. *Advances in Materials Technology for Fossil Power Plants.* 2005 ASM International.

[5] Shingledecker, J. *et al.* Materials Technology to Enable High-Efficiency Advanced Ultrasupercritical (A-USC) Steam Power Plants. "Advanced Technologies & Best Practices for Supercritical Thermal Power Plants." Partnership to Advance Clean Energy-Deployment (PACE-D) Technical Assistance Program (U.S. AID), 2013.

accelerate the design, development, characterization and standardization of alloys like Inconel and stimulate faster and greater deployment into the marketplace.

Separation products

Advanced materials that can increase the efficiency of separations processes could have an outsized impact on the energy and manufacturing sectors. Sorbents and membranes are two types of products used in applications such as carbon sequestration, fuel cells, chemical processing, and removing impurities from fluids ranging from power plant flue gas and water filtration.

Figure 2: PEEK Hollow fiber membrane contactor developed to increase the efficiency of carbon capture from power plant flue gas
Source: Li, S. et al. 2014

Membranes like the poly (ether ether ketone) (PEEK) hollow fiber membrane can be used to separate carbon dioxide (CO_2) from flue gas, which is then absorbed into a liquid.[6] By supporting further study and development of separation products or increasing access to tools such as high-throughput simulations and experimentation, a national initiative could unleash the potential of advanced materials for separation processes – verifying products that can separate desired components at preferred conditions such as higher pressures and temperatures and low concentrations, with reduced degradation over time.

Coatings

Coatings can increase the durability and corrosion resistance of metals and other materials, increasing the lifetime of products and reducing downtime of processes across the energy and manufacturing sectors. Advanced materials for coatings are especially important for extreme environments, where resistance to degradation by high temperatures and corrosive chemicals must be explored in addition to other desirable coating qualities such as good adherence while remaining inert with many substrates including varying types of metals and alloys, and low toxicity.

Figure 3: Aluminum fins from a geothermal power plant subjected to 24,000 cycles of exposure to briny conditions with: no protective coating (left), nano-coating with a low level of Cerium Oxide (middle), and a nano coating with a higher concentration of Cerium Oxide (right).
Source: Larsen, KR, 2009

[6] Li, S. et al. "Post-combustion CO_2 Capture Using PEEK Hollow Fiber Membrane Contactors." 2014.

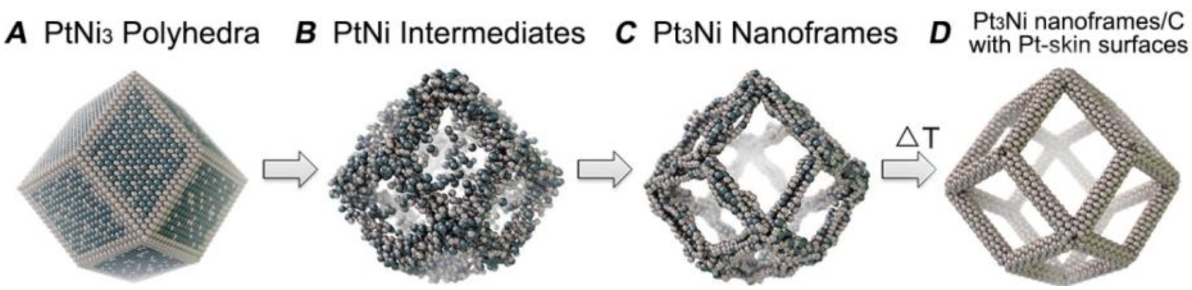
Coatings like an ultrathin coating with rare-earth metal oxide nanoparticles mitigate the corrosion effects from brine in aluminum fins in air-cooled condensers at geothermal power plants.[7] By increasing access to materials data and expertise, modeling and simulation capabilities, and high throughput experimentation tools, a national initiative could continue the discovery of durable, economical, and more environmentally friendly coatings in addition to efficient and optimal methods for their application to substrates.

Catalysts

Catalysts are commonly used in technologies and processes to increase the rate of desired chemical reactions and inhibit undesired reactions across sectors including chemical and petrochemical industries, the pharmaceutical industry, and power production for electricity and vehicles. Research continues to race forward in catalysis to find methods to create more effective and less expensive catalysts, find methods to increase exposure to catalysts, and reduce the degradation of catalysts from poisons and long periods of exposure to potentially harsh environments.

Catalysts like the nanoframe platinum nickel catalyst generated for fuel cells, have been designed and produced to use roughly 85% less platinum while enjoying over 30 times the catalytic activity of platinum dispersed on carbon.[8] Further developments in catalysis could benefit from increased access to tools and expertise in a national initiative, moving forward new discoveries such as these platinum nickel nanoframes into manufacturable and deployable products more quickly and with less expense.

Figure 4: Illustrations showing the evolution of platinum/nickel catalyst from a solid polyhedral structure to nanoframes with platinum-enriched skin.
Source: Lawrence Berkeley National Laboratory, 2014.



[7] Larsen, KR. "Corrosion-resistant coatings incorporate metal oxide nanoparticles." *Materials Performance*, 2009.
[8] "Big Step for Next-Generation Fuel Cells and Electrolyzers." Lawrence Berkeley National Laboratory, 2014.

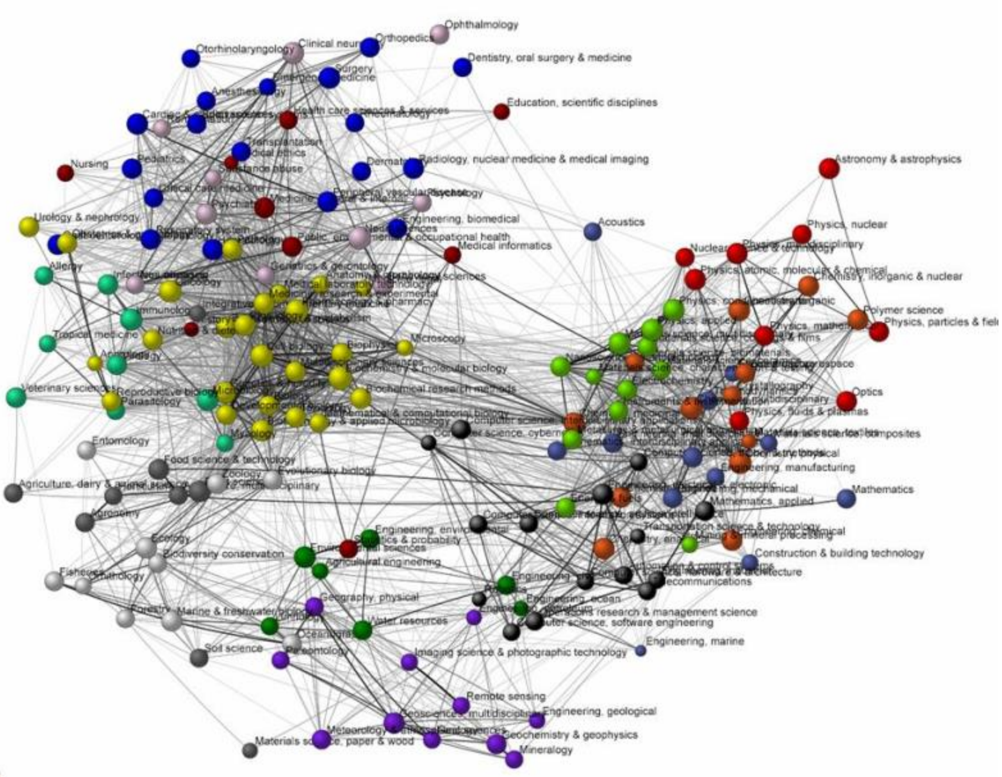
Potential Activities in a National Advanced Materials Initiative

Another potential way for the Department of Energy to create a national initiative to accelerate the design, development, manufacture, and deployment of advanced materials is to support specific activities that apply to a wide variety of material classes. These activities could include resources within our unparalleled U.S. national laboratory complex and the university research system. Within the wide-array of expertise, capabilities and scientific user facilities housed at these global centers of innovation and excellence, the Department of Energy is working to leverage advanced manufacturing expertise and infrastructure in addition to developing tools with the potential to accelerate advanced materials manufacturing from materials discovery through deployment. A national initiative could be designed to include some of the following activities:

Mapping public sector capabilities

The Department of Energy Technology Transfer program provides a mechanism to search for expertise and facilities in specific scientific and technological areas of interest through the DOE national laboratories.[9] The Department of Energy, could fund and expand this effort into a full map of public sector capabilities through a national initiative, potentially even paired with a matchmaking or concierge service that could help private sector organizations find the relevant tools and expertise within the national laboratory and university research ecosystems.

Figure 5: Institute for Scientific Information (ISI) subject categories connected by correlating citations
Source: Leydesdorff.net

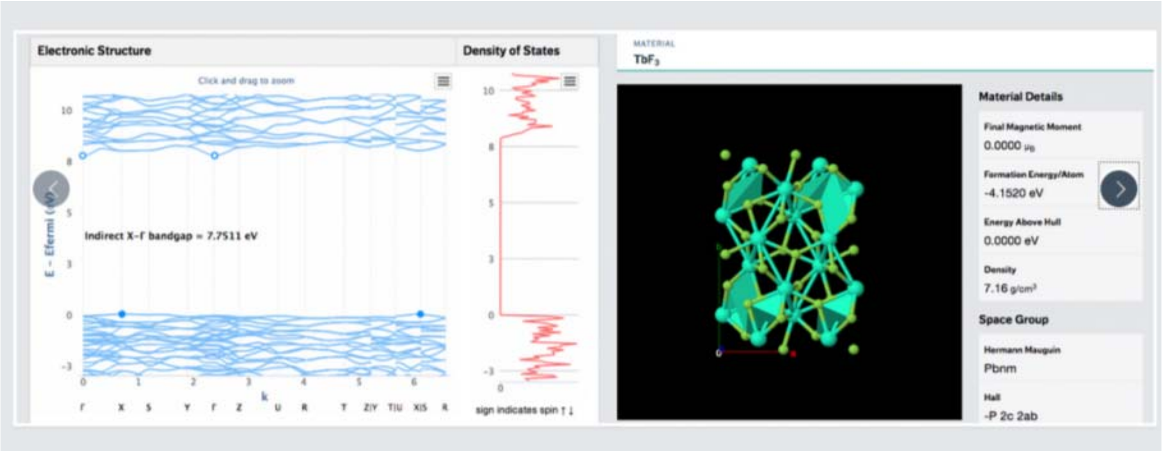


9 Department of Energy, http://techtransfer.energy.gov/doelabwork.

Create a materials data repository

The Materials Project,[10] a core program in the Materials Genome Initiative, harnesses the power of supercomputing and data to provide open web-based access to computed information on known and predicted materials as well as powerful analysis tools to inspire and design novel materials.

Figure 6: Information available on Terbium Fluoride (TbF_3) from the Materials Project
Source: www.materialsproject.org



There is a great potential to unleash a surge in American prosperity and productivity by continuing and expanding the Materials Project as part of a national initiative. Integrating knowledge from many types of materials research across the research and development ecosystem into one central repository could create a searchable system could reduce redundancies in research and shorten the time to discover appropriate materials for a given purpose. In addition, being able to also access computer software and hardware tools and expertise to complete computations using readily available and intelligible data could benefit both university and national laboratory based research in addition to research for private sector companies.

Increase access to tools

The Department of Energy's national laboratory complex and supported university research programs are fountains of expertise, capabilities, and scientific user facilities that can be applied to accelerating the design, development, manufacture, and deployment of advanced materials. These resources have a history of partnering with industry to overcome industry problems, and while many good examples of success exist,[11,12,13] the broader community has not yet benefited.

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[10] The Materials Project, https://www.materialsproject.org/.
[11] Council on Competitiveness. Case Study: Goodyear Puts the Rubber to the Road with High Performance Computing. 2009. More information available at: http://www.compete.org/publications/detail/685/goodyear-puts-the-rubber-to-the-road-with-high-performance-computing/.
[12] Albuquerque Business First. "Los Alamos honors team for work with P&G." August 2013. Available at: http://www.bizjournals.com/albuquerque/blog/morning-edition/2013/08/los-alamos-honors-team-for-work.html.

Through a national initiative to accelerate the design, development, manufacture, and deployment of advanced materials, the Department of Energy could clarify the methods to approach and use these capabilities at the national laboratories and university research programs, or fund projects for individual companies to use these capabilities towards solving industry-relevant problems.

Figure 7: The Advanced Photon Source at Argonne National Laboratory

Source: Argonne National Laboratory

High-throughput simulations and experimentation

A national initiative could help develop and demonstrate coupled high-throughput simulations and experimentation techniques for advanced materials – parallelizing simulations and experiments to examine a large space of interest over a short period of time. By integrating these methods and making the infrastructure available, the initiative could provide a different approach to materials research that could, more quickly and with less expense, help discover relevant and novel materials for existing industrial needs.

Figure 8: The new "Catalyst" supercomputer available at Lawrence Livermore National Laboratory for collaborative projects with American industry pairs Big Data with high performance computing power.

Source: High Performance Computing Innovation Center at the Livermore Valley Open Campus

Figure 9: Using the power high-throughput experimentation to simultaneously synthesize or test hundreds of materials.

Source: SYMYX PHOTO, American Chemical Society 2001.

[13] Los Alamos National Laboratory. Chevron, GE form Technology Alliance. February 2014. Available at: http://www.lanl.gov/newsroom/news-releases/2014/February/02.03-chevron-ge-tech-alliance.php.

Looking Forward

AEMC Partnership *Materials Manufacturing Accelerator* Dialogue 1 presents potential ways to focus in on ways to bring advanced materials into manufactured processes and products and deploying these materials into the marketplace. Suggesting focus on specific classes of materials, specific capabilities for all advanced materials, or specific tools and activities that can be applied to large swaths of material classes – or a mixture of the three – the Council and the Department of Energy look forward to hearing the perspectives of decision makers on the best methods to accelerate the use of advanced materials. Dialogue participants are asked to consider the following key questions:

1. What barriers hinder development and deployment of advanced materials in your company? In your sector?
2. How can the public and private sectors work together to create a national initiative to integrate advanced materials into manufactured processes and products better, faster, cheaper?
3. How can the *Materials Manufacturing Accelerator* initiative encourage participation across the private sector – across industries, companies of all sizes, and technological expertise?

The dialogue on May 8, 2015 at the Food Innovation Center of Oregon State University allows the Department of Energy to gather feedback from the community of stakeholders in advanced materials. The Department of Energy will consider this feedback as it moves forward in the creation of a Materials Manufacturing Accelerator initiative with organizations across the innovation ecosystem.