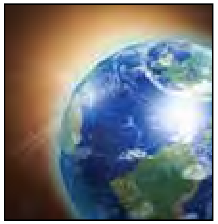
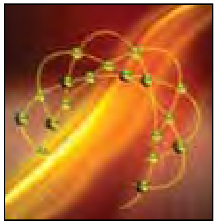
Materials Research Enabling Clean Energy and Sustainable Development

MATERIALS RESEARCH SOCIETY
Advancing materials. Improving the quality of life.

2011 World Materials Summit
& STUDENT CONGRESS

L'Enfant Plaza Hotel | Washington, DC | October 9-12, 2011





Following up on the success of the World Materials Summits held in Lisbon, Portugal (2007) and Suzhou, China (2009), participants of the 2011 World Materials Summit gathered in Washington, D.C., from October 9-12 to exchange ideas and develop plans for materials scientists to tackle the major challenges in energy and sustainable development across the globe. The participants included approximately 100 expert scientists and policymakers from Asia, Europe, India, Mexico, Africa, the United States, Canada, South America and other parts of the world to lead the discussions and recommend solutions to some of the most daunting problems we must now confront.

But to ensure that these efforts continue far into the future, it is not enough to include only those with the most years of experience behind them. The younger generation of scientists must also be engaged. This Summit differed from its predecessors by including a Student Congress of 45 of the best and brightest graduate students and post-doctoral fellows from around the world. These individuals were chosen by a competitive application process to attend the Summit, learn from the experts, discuss the issues in student panels, and contribute their own recommendations to the Summit's formal declaration. By joining the voices of the next generation with those of the reigning experts in the fields of materials, energy, and sustainability, the Declaration that follows was strengthened by the long term commitment of both groups to secure the world's energy future through sustainable materials usage and development.

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VISION

It is an inherent right of everyone on Earth to have access to clean energy and potable water in a sustainable way. Achieving this goal is a global endeavor that will require international coordination, cooperation and collaboration. Materials play a critical role in enabling viable solutions to these problems.

World Materials Summit Declaration

The 2011 World Materials Summit in Washington D.C., USA, identified opportunities and mechanisms to facilitate international cooperation focused on addressing materials science needed for solutions to the critical needs of energy and water. The Summit was coupled to an International Student Congress providing key insights into opportunities for international networking, education and outreach.

To achieve the vision, the Summit had the following key observations:

- Mechanisms need to be developed for partnering, not only across international boundaries, but also across disciplines; solutions and their adoption will require partnering of materials scientists, sociologists, economists and policy experts as an integrated activity.
- Many fields need uniform international standards, many of which currently do not exist. Materials research societies should be conveners for these activities. They should also look at the possibility of developing metrics for sustainability.
- Energy efficiency, if broadly enhanced by materials science, represents one of the key opportunities for the materials research community to engage the global communities of users and developers in areas such as buildings, lighting, and recycling. Recycling technologies are crucial opportunities for international collaboration.
- Future research and development must consider the abundance of materials and their accessibility. Green processing must be considered for new materials. Information resources, such as a Google-like prospector, are needed to assess resource availability. Developments should be cast in the context of potential global impact.
- Water is a critical resource for many technologies and is critical for the quality of life. International collaboration can enable the application of materials science and engineering directly to the purification, processing, and delivery of water worldwide.
- Sustained international cooperation and funding must be encouraged through government policies to move technologies to deployment. Mechanisms need to be put in place that facilitate collaboration throughout this process.
- Public outreach, a role of growing importance for the materials community, should be facilitated through international collaboration. The materials science community must develop tools and educational materials to foster public understanding.
- All forms of energy generation must be considered, without bias, in the context of societal impact, true risks, costs and sustainability.
- Scientists have a clear obligation to be advocates of this vision, and a personal responsibility to enact these principles.

Student Congress General Recommendations

Energy Statement

Provide unbiased reporting and analysis of energy technologies based on standardized sustainability metrics such as: greenhouse gas (GHG) emissions (actual and potential reductions), lifecycle analysis, risk assessment and reduction, and region-specific assessments of potential technologies.

Market and Economics

Address global imbalances in innovation and manufacturing through targeted funding to translate basic science into products, encouraging economic education, and initiating goal-based prizes for breakthrough materials.

Education Statement

Support and maintain an online Global Resource Center for Sustainability (GRCS) that will provide educational lectures and demonstrations.

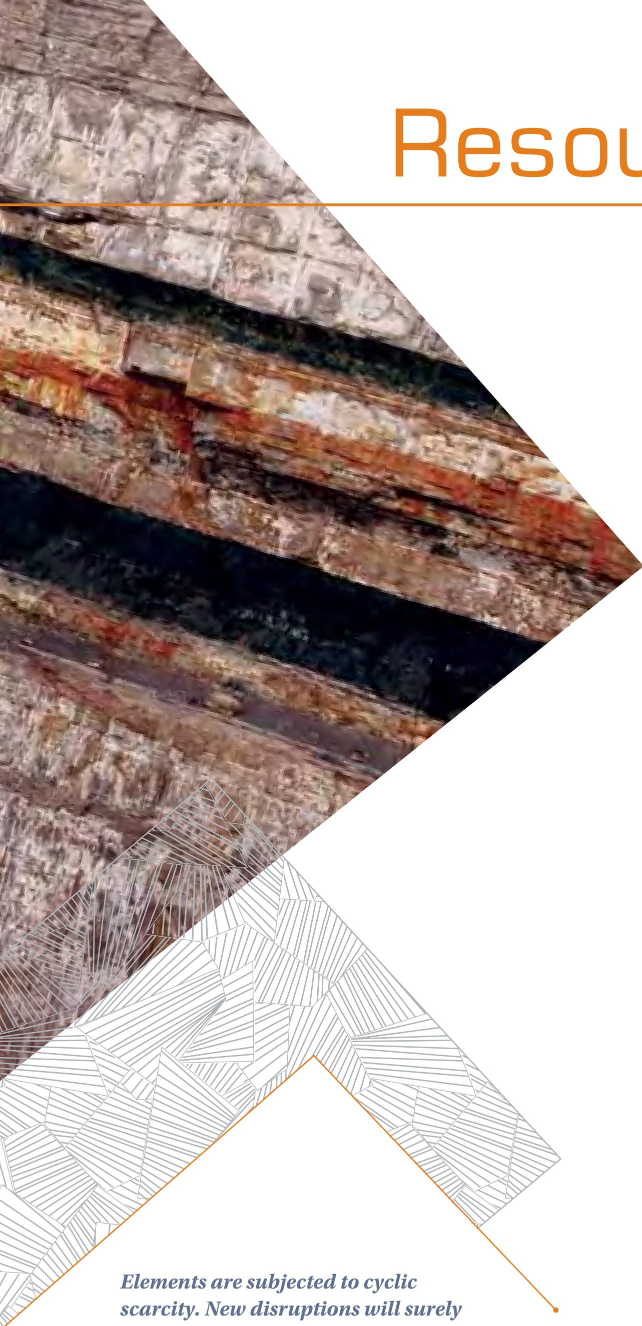
Outreach Statement

Empower students to advocate for energy and sustainability to reach both policymakers and the general public in ways which are relevant and clear.

Water Statement

Develop appropriate technologies, educational awareness, and policies to encourage efficient water purification, management and access for a growing world population.

Resource Assessment



One concept used by economists to evaluate sustainability is "social metabolism," which refers to the overall balance of materials consumption, energy output, and waste products of a socioeconomic entity. Like a biological metabolism, which depends on a continuous throughput of materials for health, society depends on a continuous throughput of materials for sustainability. Materials are extracted through mining, used to produce energy or durable goods, and eventually end up as waste in a landfill or emissions in the atmosphere. But in a closed system like our planet, where resources are limited and unevenly distributed, a better understanding of the sources of materials, the ways they are processed, and their reuse through recycling are increasingly critical factors in achieving a sustainable society.

Of particular current interest is the shortage of rare earth elements, which are used in electronics, magnets, metal alloys, catalysts, glass, and other products. China is now the largest supplier of the 17 rare earth elements, particularly those in the lanthanide group of the periodic table, identified as "energy critical" in several studies. A south China clay happens to contain all 17 of these elements. "Each nation is assessing its critical element list," said Frances Houle of the Lawrence Berkeley National Laboratory at the 2011 World Materials Summit. "Each list is different, but all of them contain the lanthanides."

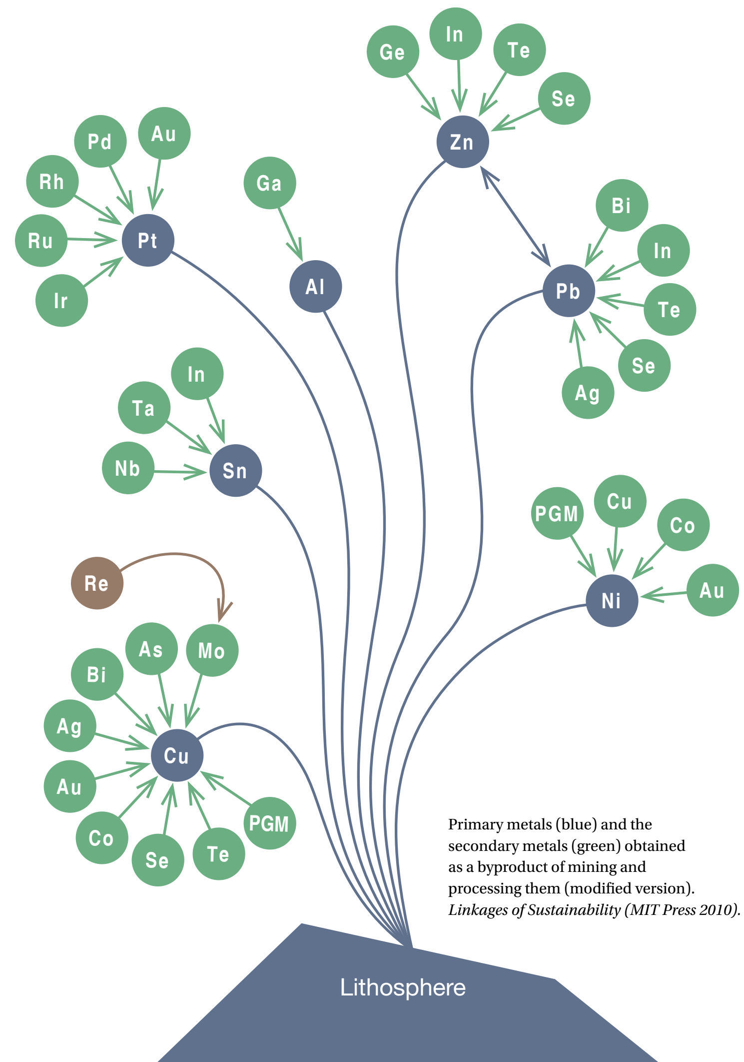
As costs rise due to low supply in the supply/demand equation, geologists are searching for new deposits of these elements, and efficient ways to extract them, while materials scientists, chemists, and other researchers are trying to develop substitute materials that are in larger supply and can do the job of replacing the critical elements.

Another example of a critical element, although not a rare earth element, is tellurium (Te). There is a known reserve of 48,000 metric tons of Te worldwide but it is not present in high concentrations in any one place. Tellurium is generally found as a trace element in copper deposits. "You have to extract and refine lots of copper to get enough tellurium for practical uses," Houle said. The element is a key component of CdTe thin films in photovoltaic devices for solar energy production, among other applications. At the other end of the lifecycle, Te and many other elements are present in such small quantities in electronic devices like cell phones that they are very expensive to recycle, although this is being done for solar panels. Research into improved processes can reduce costs or alternative materials can be developed.

A sustained commitment to materials science research is necessary not only in solving current critical element problems, but also for future ones, as these shortages tend to be cyclical. New scientific developments in the lab could add other elements to the critical list while removing some of the current ones; discovery of large deposits of a critical element might also chase it off the list. Designing products with recyclability in mind, and increasing a product's durability and lifetime, could decrease the demand for critical elements and improve the chances for sustainable development.

Elements are subjected to cyclic scarcity. New disruptions will surely happen. We need a sustained commitment to materials science to handle these disruptions.

—Frances Houle
Lawrence Berkeley National Laboratory
2011 World Materials Summit, Resource Assessment Panel



Primary metals (blue) and the secondary metals (green) obtained as a byproduct of mining and processing them (modified version). *Linkages of Sustainability (MIT Press 2010).*

Looking toward 2030, the Resource Assessment panel announced a long term vision of "Having the raw materials needed for energy technologies when they are needed, provided sustainably, at an affordable price."

Challenges

The panel identified four major topics for detailed discussions: mining, recycling, materials substitution, and analysis. The major research and technological needs and challenges in support of the long term vision in each of these categories are

- Mining: developing sustainable, efficient mining methods; increasing understanding about ores containing rare elements; establishing appropriate regulations
- Recycling and materials substitutions: increasing systematic knowledge about appropriate methods
- Analysis: increasing and organizing information on materials, resource needs and processes

Recommendations

- Reduce risk by enhancing knowledge of natural resources and materials needs of new technologies. This will require increased communication among suppliers, economists and technologists.
- Develop information on resources and reserves, and on actual consumption for new energy technologies; reliable and timely information is required to enable accurate projections of needs.
- Develop geoscientific techniques to better identify new sources of scarce materials. Emphasize "surgical" mining rather than extracting large amounts of rock for a little final product.
- Establish a life-cycle assessment methodology that will consider a process or product from extraction at the mine through recycling to evaluate the impact on sustainability at each step.
- Investigate more efficient and benign extraction and refinement chemistry.
- Enhance recycling and separation processes (chemical, biological, physical).
- Perform research on properties of recycled metals and processes for their use.
- Learn efficient chemistries using CO_2 as a raw material.
- Develop technologies for more efficient capture of CO_2 from process waste gases.
- Investigate substitutions for rare elements through materials discovery involving composition, structure and morphology.

Rare-earth oxides, clockwise from top center: praseodymium, cerium, lanthanum, neodymium, samarium, and gadolinium. *Wikimedia Commons.*

Renewable Energy

Renewable energy sources are those whose supply is continually being replenished, including solar, wind, geothermal, hydroelectric, and biomass sources. This is in contrast to fossil fuels, which will inevitably run out someday, regardless of technological improvements or discovery of new resources. Renewable resources are generally locally available, eliminating the need for costly imports. They are capable of entirely replacing the quantity of energy we currently derive from fossil fuels, and except for the traditional burning of biomass (typically wood), produce little greenhouse gas emissions. Yet renewable energy comprises only 19% of the world's energy supply, and only 8% of that of the United States. About two-thirds of the world's 19% comes from traditional burning of biomass, so it is a remnant of earlier times and technologies instead of an advance. Only 0.7% of the world's energy needs are supplied by a combination of solar, wind, geothermal, and advanced biomass technologies. "Despite its advantages, renewable energy is hardly used," said George Crabtree of Argonne National Laboratory and the University of Illinois at Chicago at the 2011 World Materials Summit.

Why is this? Fossil fuels have been around longer, are better understood, and require only some form of relatively inexpensive combustion to extract their energy. Renewables, however, are new and less understood, and they require high tech materials and chemistry (e.g., photovoltaics, electrodes, superconductors, and catalysts) for energy extraction. "Complex, high tech materials are both the driver and the bottleneck for renewable energy," Crabtree said.

It is also important to realize that renewables are still in their infancy, having started with solar panels for NASA's spacecraft in the 1960s. There is much room for improvement in these technologies, and materials scientists and other researchers are making great progress in increasing the efficiency of energy conversion from renewable energy sources of all types.

Solar power can come from solar electric conversion, which involves photovoltaics (solar cells) to convert sunlight into electricity; from solar fuel, which is essentially an artificial form of photosynthesis; and from solar thermal technology, in which a contained fluid heated by the sun can be used to generate electricity. Current photovoltaic technology has a 32% efficiency limit, but that is only for single junction cells generating one excited electron per photon absorbed. Researchers are investigating other solar cell device approaches, including cells with multiple junctions, multiple bandgaps, and multiple excitons per photon to achieve efficiencies greater than 42%. Inexpensive organic photovoltaics, solar-powered catalysts, and concentrated thermal solar technologies show great promise.

Wind power has a theoretical efficiency limit of 59%; current wind technologies have reached 35-50% levels. Researchers are investigating lighter weight, stiffer composite turbine blades to increase energy output and reduce its cost. The other challenge in wind is in the generator. Superconducting, gearless generators that have a higher current density and twice the output power of conventional gearboxes of the same size and weight are being tested.

Achieving the European Renewable Energy Council's goal of 20% of electricity from renewable sources by 2020 will require ten times the present installed capacity of solar and wind devices. Geothermal, hydroelectric, and biomass resources could also contribute to the mix, and much research is being done in these areas.

Despite all the advantages of renewable energy sources, they are hardly used.

—George Crabtree
Argonne National Laboratory
2011 World Materials Summit, Renewable Energy Panel

Deflection of a cantilevered 45-meter blade under distributed static load testing. *Fundamentals of Materials for Energy and Environmental Sustainability (2012).*

The Renewable Energy panel focused on the following four areas, with a concentration on solar energy issues: materials challenges, R&D, manufacturing, and deployment. The panel developed the following policy recommendations:

- The Materials Science Community should develop international and public-private partnerships to generate the Google Prospector which is envisioned as a public domain global inventory of the availability in the earth's crust of critical materials needed for renewable energy technologies. Funding is required to develop the tools to identify the location and estimate the size of local material reserves, to map their distribution, and to provide local validation.
- The Materials Science Community needs to champion educational outreach programs touting the necessity of end-of-life materials recovery practices. The community should make life cycle materials engineering a focus area within its current portfolio of symposia and workshops.
- An international coalition needs to establish continental testing and validation centers (i.e., NREL-Sandia, AIST, Fraunhofer-ISE, Africa, China, Australia, India, Mexico) to ensure a level playing field and consumer confidence. They should implement a series of international workshops to establish the framework of this new international network. Also, the coalition would have to establish a network of funding sources (i.e., governmental and private trade associations) to support these centers and activities.
- In symposia and workshops directed toward planning for renewable/grid interconnectivity, we include discussion of opportunities in developing areas and not focus exclusively on established grids.
- Professional materials research societies should set up a competition to identify the best groups in organic photovoltaics from around the world and connect them via an international coordinating framework funded to make progress in this area.

The panel also provided R&D and materials development recommendations.

R&D:

- **Organic Photovoltaics Development**
  Organic photovoltaics are among the most promising and most challenging solar cell technologies. Their rapid progress in raising efficiency to near 10% shows their technical promise, while the diversity and complexity of the organic materials available for donors and acceptors shows their technical challenge. The promise of low cost flexible solar cells, the wide horizon of basic materials challenges and the early, precompetitive stage of research justifies a strong and coordinated international development effort.
- **Materials Availability**
  There is strong international demand for a global inventory of the availability in the earth's crust of critical materials needed for renewable energy technologies. Such an inventory or "Google Prospector" would guide basic materials research for innovative renewable energy technologies to focus on earth-abundant materials capable of scale-up to TW production levels and away from materials whose scarcity limits the ultimate energy impact of associated new technologies to insignificant or token levels. The Google Prospector should be in the public domain and cover all renewable energy materials being used or under consideration for new technologies. The strong interaction of mining and production of primary and secondary (by-product) materials is a key feature of the proposed Google Prospector analysis; restrictions and opportunities arising from this byproduct interaction have not been adequately explored.

Materials development:

End-of-life recovery of critical materials is a key feature of renewable energy practice that must be designed into the lifecycle of a product before its birth. End-of-life materials recovery minimizes environmental impact while reducing the use of critical materials that may limit the scale of deployment of renewable energy technologies. The many approaches to end-of-life materials recovery, including re-use, re-manufacturing and recycling, need to be carefully analyzed and applied at the design stage. These kinds of end-of-life reverse engineering to allow materials recovery are fundamental design principles that need widespread international support to become standard practice.

UNI-SOLAR® thin film solar panels being installed on the roof of a Coca-Cola bottling plant in Los Angeles, California. *UNI-SOLAR®*

An organic photovoltaic solar cell ribbon produced by Konarka Technologies, Inc.

Energy Fuels

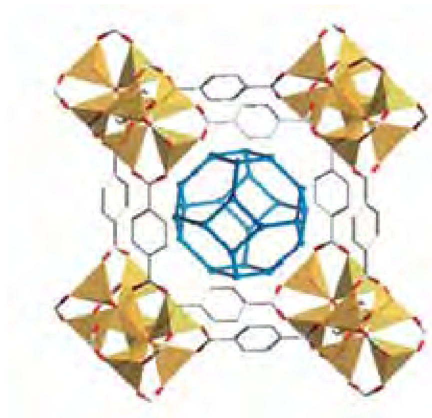
Energy fuels are sustainable liquid fuels made by biomaterials processing, various catalytic processes (including enzyme catalysis and photocatalysis), and conversion of CO_2 captured from industrial processes into hydrocarbon fuels. Though currently only a minute portion of the renewable energy mix, energy fuels could make a more substantial contribution as these processes become optimized through technological developments.

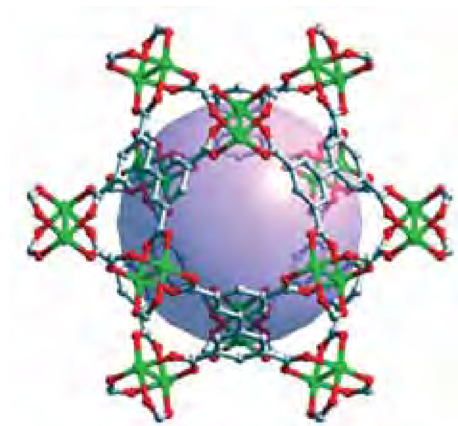
A recognized success to date in biofuels has been Brazil's production of ethanol from sugarcane, which amounts to 25 billion liters of ethanol per year. Because sugars are readily converted to ethanol by fermentation, processing costs are low, and profits are now made without subsidies from the Brazilian government. Automobiles designed to run on blends of gasoline and ethanol—including 100% ethanol—have made this biofuels process a viable one in Brazil. The conversion of corn to ethanol in the United States has been less viable because corn is a starch that must be converted to sugar first before fermentation to alcohol. The United States government has subsidized the bio-ethanol industry and protected it with a tariff on imports.

Issues of deforestation to grow biomass for fuels, and concerns about using foodstuffs for fuels have further slowed the penetration of this renewable source of energy into the market. One solution is to grow inedible biomass sources like switchgrass and jatropha, a hardy plant common in Africa, South America, and southern Asia, instead of foodstuffs for conversion to fuels. A major challenge here lies in breaking down the tough cellulose, hemicellulose, and lignin components of the cell walls of plants. This process is controlled by enzymes (biological catalysts) such as cellulases in nature, but more efficient catalysts are needed to increase the yield and reduce the costs of this process on an industrial scale. Hence, researchers are trying to engineer new enzymes to more quickly catalyze the breakdown of cellulose into sugars. Biomimetic systems and materials could thus fill an important need in energy fuels production. Other researchers are working on photocatalysts that use sunlight to split water, resulting in hydrogen that can be used in fuel cells or for liquid fuel synthesis.

Catalysis is also a major component of technologies that turn coal, natural gas, or biomass into syngas (a mixture of hydrogen and carbon monoxide). The reaction of the H_2 and CO on an iron catalyst to produce liquid hydrocarbon fuels is the key to the Fischer-Tropsch process that Sasol in South Africa has long used to make synthetic gasoline and diesel fuels. More expensive catalysts containing platinum or cobalt have been investigated to improve the yield of this process, and the search for better catalysts continues.

Once carbon capture technology has reached a point where industrial quantities of CO_2 are available as a raw material for reaction, it is likely that this CO_2 will be reacted with H_2 to create liquid fuels. This could turn the most notorious of greenhouse gases into a valuable source of energy fuels.





Metal-organic frameworks (MOFs) may offer superior properties for hydrogen storage because of the enormous variety and flexibility of the frameworks. *Ruqiang Zou and Yusheng Zhao*

The perception that "ecomaterials" are materials for environmental protection is misleading. In fact, all materials and processes have environmental impacts.

—Duan Weng
Tsinghua University
2011 World Materials Summit, Energy Fuels Panel

Recommendations:

The Energy Fuels panel recommended that materials and energy researchers:

- Prepare now through research and development for a transition to biofuels.
- Discover improved catalysts for energy fuels.
- Create an enhanced international environment for translational energy fuels science.

The major areas of study for energy fuels include biomaterials, bio-processing, optimization of biofuels production, enzyme catalysis, catalysis, photocatalysis, carbon capture, and materials for safe fossil fuel production.

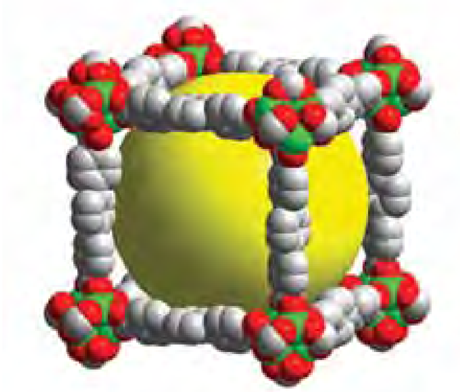
In the "bio" regime, the following research areas should be the points of focus: (1) biomaterials – (feedstocks for biofuels, biomaterials structure, lipids and lignocelluloses, biomaterials deconstruction); (2) bio-processing (metabolic engineering, biomimetic systems and materials, synthetic biology); and (3) optimization of bio-fuels production (land, soil, water and resource use, cultivation and processing materials).

The catalysis area should focus on (1) enzyme catalysis (cellulases/lipase, enzyme engineering); (2) catalysis (fundamental understanding for prediction of catalytic properties, more efficient use of fossil fuels, greener processing); (3) electrocatalysis (synthetic fuels); and (4) photocatalysis (artificial photosynthesis).

CO_2 conversion requires investigation of (1) catalysis (better Fischer-Tropsch and water gas shift processes, methane reforming with CO_2); (2) materials for CO_2 capture; and (3) materials for safe fossil fuel production.

The panel also noted the following:

- An interdisciplinary approach is required in terms of basic/experimental/application/commercialization and communication.
- New funding models are required for interdisciplinary and translational approaches to research and education. For example, EU R&D through Innovation and NIH Translational Programs.
- Student interdisciplinary/transitional teams need a new funding mechanism.
- Reduce "hype" and replace it with effective science, technology, economics, and energy balance evaluation.
- There is a need for worldwide implementation of programs for sustainable energy research and development. For example, consider developing a "Scientists and Engineers without Borders" group modeled on the highly successful Doctors without Borders.
- International, IP neutral, catalyst testing laboratories are required to advance energy fuels technologies more rapidly and comprehensively around the world.



Metal-organic framework (MOF).
Ruqiang Zou and Yusheng Zhao

Nuclear Energy

Since the former USSR's Obninsk Nuclear Power Station first generated electricity for the grid in 1954, the number of civilian nuclear plants has grown to 441 worldwide (as of October 2010), with a collective delivery capacity of 375 GW, and no greenhouse gas emissions. This amounts to 13.5% of current global power. Given the estimates of global energy needs by 2030, if this percentage remains the same we will need 950 nuclear plants to generate 4100 TWh from nuclear sources, according to V.S. Arunachalam of India's Center for Study of Science, Technology and Policy, who spoke at the 2011 World Materials Summit. The International Atomic Energy Agency says that 44 nuclear reactors are currently under construction, and 70 more are planned in the next 15 years. This rate of growth will leave the world far short of nuclear power capacity in 2030, especially given that approximately 150 existing reactors will need to be replaced by then.

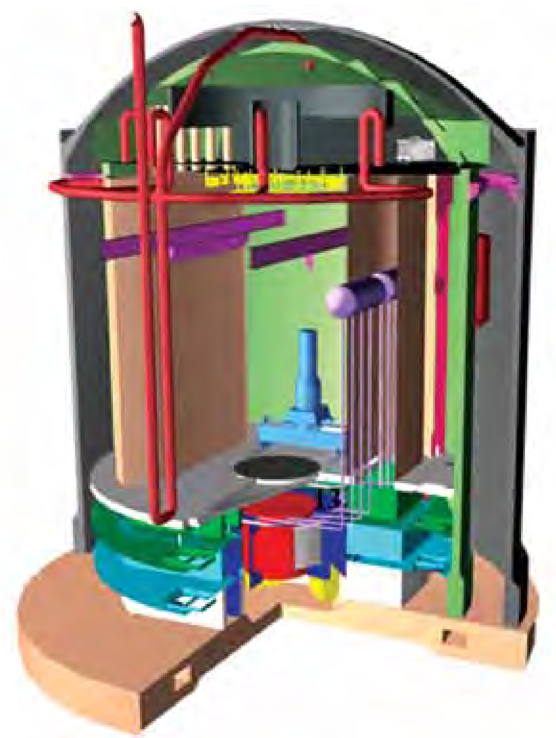
The nuclear future is further clouded by safety concerns. The explosions at the Fukushima Daiichi nuclear plant in Japan in 2010, brought on by a powerful earthquake and tsunami, have only increased those concerns. Germany announced it will close all of its nuclear power plants by 2022 because of the perceived unacceptable risk. Because 78% of the electricity generated in France comes from nuclear power plants, France remains committed to this power source. China, Russia, and India are proceeding with plans for fast breeder reactors, with the Prototype Fast Breeder Reactor scheduled to go critical in Kalpakkam, India, around the beginning of 2013.

Arunachalam, while aware of the potential dangers of complex nuclear plants, says that "we must learn to live with complex systems." Enhancements to safety offered by the latest Generation IV nuclear reactors are encouraging. In a Generation IV supercritical water-cooled reactor, for instance, the nuclear fuel will be in the form of microspheres, which will prevent fission products from leaking out. Advanced heavy water reactors will have no pumps in the system and a negative void coefficient (a number used to estimate how much the reactivity of a nuclear reactor changes as voids [typically steam bubbles] form in the reactor coolant). Using sodium as a coolant instead of heavy water can also prevent void problems.

A promising supercritical reactor fuel will be all microspheres, so fission products won't leak out

—V.S. Arunachalam
2011 World Materials Summit, Nuclear Energy Panel

Materials science can help to enhance the safety of nuclear systems by developing a better understanding of the properties of irradiated metals. Neutrons generated by the nuclear reaction will knock atoms from their positions in the lattice of the metal cladding that holds the nuclear fuel, potentially leading to dangerous defects and gas inclusions in the metal over time. Understanding and preventing such defects could enhance the safety of the reactors. Also, finding a replacement for the zirconium-based alloys that are used for the cladding could minimize explosions in the event of an accident. Arunachalam pointed out that hydrogen released by the reaction of zirconium with steam—not a nuclear core meltdown—caused the explosions at both Chernobyl and Fukushima. Finally, understanding thorium, which is three times more abundant in nature than uranium and has the potential of being a superior nuclear fuel, with less waste and proliferation risk, remains a challenge that materials scientists are investigating.



Generation IV Advanced Heavy Water Reactor uses thorium instead of uranium, thereby reducing nuclear proliferation concerns. *Department of Atomic Energy, India.*

The panel on nuclear energy stated "access to a fast(er) neutron source is critical for both future advanced fission and fusion system development." They also announced three broad conclusions:

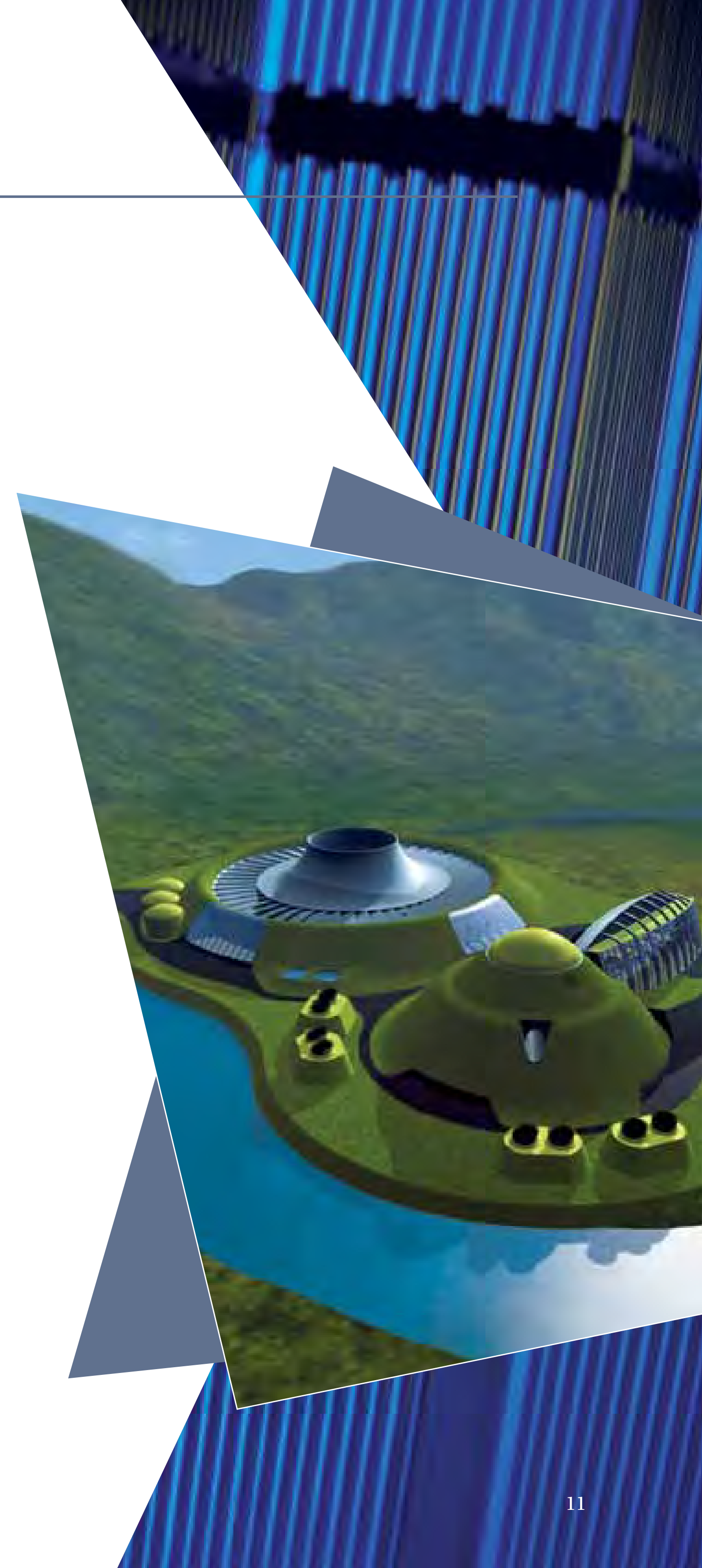
- Although the approach of individual countries will differ, nuclear power usage is likely to be a continued source of energy. The relative public acceptance of risk balanced against energy security, informed by the role of specific public policy approaches in each country, will largely determine the specific national response. Informing the public and policymakers on the importance and relative risks of nuclear energy versus other energy sources is critical to getting an informed decision.
- Meeting materials challenges is a key technology response to provide "safer" nuclear energy, specifically radioactive material control, extended life plant operation, and safety associated with decay heat removal in the extreme case of station blackouts. Solving these issues, possibly through materials science solutions, will increase the chances of public acceptance of nuclear energy.
- The user facility concept, providing access to high-end capability (test reactors, synchrotron light sources, neutron scattering sources) that can handle radioactive materials is important and, in conjunction with advanced modeling opportunities, offers a new paradigm for advancing the insight into radiation damage while simultaneously motivating a next generation workforce. However, the user facility concept must have extremely low costs and high performance.

The panel announced two major recommendations:

- To take advantage of the carbon-free generation possible through the use of nuclear energy, nuclear systems must continually strive for improved safety, acceptable economics, reduced proliferation, and minimization of the waste stream. Improving materials technology, and subsequently informing the public and policymakers of the improvements, is critical to meeting this goal. Of specific note is the need to evaluate, analyze, interpret, and respond, via materials improvements, to the specific safety challenges identified in the Fukushima accident.
- Building active collaborations among the countries performing nuclear research will expedite material solutions. Including major facilities in France, Japan, China, India, the United States, and other countries with significant nuclear research infrastructure would be optimal. Providing mutual facilitated international access coupling the best scientific ideas with unique capabilities such as test reactors, and synchrotron and neutron scattering sources that can handle radioactive materials, is important. In conjunction with advanced modeling opportunities, the "user facility" model offers a new paradigm for advancing material performance while simultaneously motivating a next generation workforce.

The panel also made a public policy recommendation:

Policymakers typically balance the opinion of technologists who advocate a technical solution and the general public who benefit and are affected by the technology choice. Informing policymakers of the ability of materials science to mitigate challenges of nuclear energy has the ability to change the balance of that decision, specifically if you change the state of the technology.



A composite of artistic renderings by Aleš Buršič presenting ideas for modern nuclear plant design. *World Nuclear News.*

Smart Grid & Storage

The electrical grid is commonly regarded by engineers as one of the most complex systems ever assembled. "Assembled" is a better description than "invented" in this case, because the grid was never conceived of as a plan in its entirety, but rather grew organically, with pieces being added where and when needed to accommodate increasing demand. And although it is common to speak of "the" grid, there is no single system that covers the globe, but many separate ones, both national and international.

Regardless of the location, all electrical grids share common problems stemming from outdated technologies. The traditional electricity grid is a uni-directional system designed to send electricity from central generators (power plants) to distributed end-users (businesses and residences). It suffers from (among other things)

•inefficiencies from transmission and distribution losses attributable to long range electricity transport and associated transformer and wire losses.

•unsophisticated metering; meters often don't report in real time, or even at short intervals, and they lack customer interfaces to enable consumers to optimize their demand.

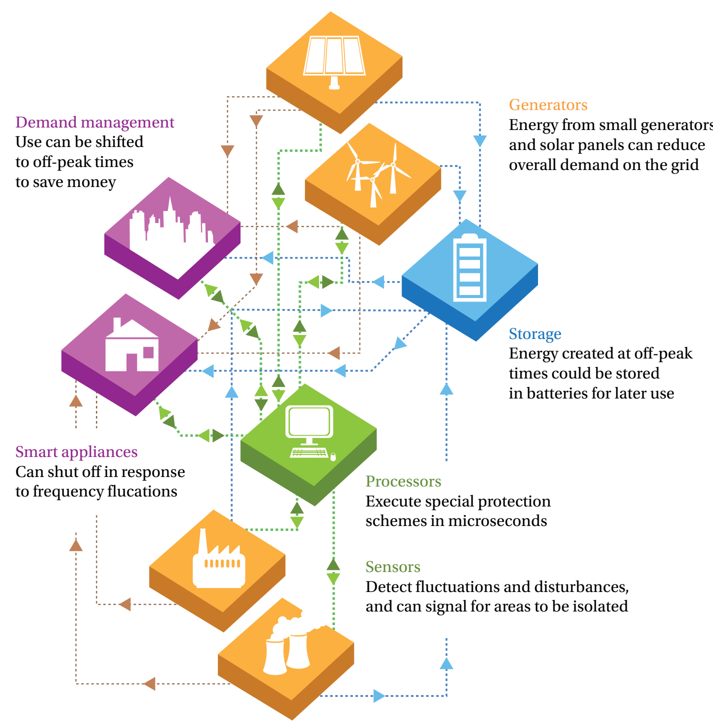
•lack of a two-way transmission, which would allow consumers to upload excess energy generated by solar cells or other renewable sources to the grid.

•lack of energy storage options to better match supply with demand.

The proposed solution is a "smart grid" that has been the subject of much policy discussion and planning in China, India, the European Union, and the United States. Though many definitions of a smart grid exist, Paul Waide of Navigant Consulting, speaking at the 2011 World Materials Summit, said that a smart grid "will use digital technology to monitor and manage the generation and transportation of electricity from all sources in order to meet the varying electrical demands of end users as efficiently as possible." It will be more resilient than today's grid, with centralized computer control of high-data-rate, two-way communication links that will enable it to be "self-healing" when a problem occurs. The smart grid will facilitate consumer participation, improve power quality, and accommodate more diverse generation options, including renewable energy sources, according to Waide.

From a materials point of view, a few of the many technological advances that will be needed include advanced sensors, particularly fiber optics sensors, capable of withstanding the harsh physical conditions inside a power plant; smart materials and structures (SMSs) based on piezoelectric polymers, shape memory alloys, hydrogels, and other materials that can sense and respond to changes in temperature, pH, or a magnetic field; nanomaterial-based systems for enhanced power storage; and advanced hardware such as gas-insulated lines for underground power cables and composite conductors that are lighter and capable of carrying more current than existing cables.

Whatever form the smart grid takes, it will not be cheap. The International Energy Agency estimated in 2010 that it will require an investment of $16.6 trillion through 2035, with two-thirds of the total investment coming from China, OECD Europe, the United States, and India.



Smart Grid—a network of integrated micro-grids that can monitor and heal itself.

In mature economies, additions to the electricity transport and distribution network face strong local opposition, hindering the capacity to improve the grid.

—Paul Waide
Navigant Energy
2011 World Materials Summit, Electrical Grid Panel

The panel provided a broad overview of their deliberations:

- The smart grid and advanced energy storage solutions are enabling technologies for both a cleaner and more efficient power grid and cleaner transportation sector. These technologies can be applied internationally to provide more reliable energy in both developed and developing nations.
- Key materials challenges include developing new energy storage materials, new methods of transmitting electricity efficiently over long distances, and control systems and smart materials for grid communications and control.

Based on these points, they concluded that "the materials science community needs to follow and be present at the discussions on smart grid development to ensure that its role is understood and to better plan its input."

The panel outlined the current status of the various elements of the challenge as a starting point for planning:

- For energy storage, the learning curve is low for compressed air and pumped storage; moderate for batteries; and medium for thermal storage.
- For electricity transmission, there's a trend toward DC cables, super high voltage transmission, ground cables, and carbon-fiber-reinforced cores in overhead cables. Longer term cable materials research needs include high-temperature superconductors, smart materials to mitigate natural risks, and heat- and flame-resistant polymer materials.
- For mobile energy needs, such as electric vehicles and hybrids, there is a need for recharging stations and off-peak charging to levelize loads.
- Other major materials-related elements include power electronics, smart meters, intelligent networks at the end-user site, and end-use interfaces.

The panel said that the present limitations to development and deployment of a smart grid are policy, market, and organizational in nature, with technology limitations being secondary. Such limitations could be overcome through governmental and industrial partnerships, common visions, and new business models.

There are a number of technology roadmaps available that attempt to guide the progress toward a smart grid. Regional roadmaps such as the Chinese plan, EU-DESERTEC, and the U.S. Department of Energy roadmap are notable, as are international roadmaps issued by the International Energy Agency and the Clean Energy Ministerial's International Smart Grid Action Network. However, the panel noted a need for progressive development of these roadmaps as new discoveries and inventions are made. They concluded that some of the regional smart-grid roadmaps could be deployed within the 2025-2050 timeframe, but that the worldwide development plans would necessarily be longer term.

Compact, high-temperature superconducting cables.

Vehicles

"Our biggest challenge is the de-carbonization of transportation," said Bernard Frois of CEA, France, at the 2011 World Materials Summit. Moving from the internal combustion engine, in which only 15% of the carbon-based fuel consumed is used to propel the vehicle, to hybrids, plug-in hybrids, electric vehicles, and ultimately to hydrogen-powered fuel cell vehicles, is one path towards increasing the sustainability of transportation. New materials for batteries and fuel cells are primary challenges along this path. Another parallel, though not carbon-free or renewable, path involves vehicles powered by plentiful natural gas. NGVAmerica, an advocacy group for natural-gas-powered vehicles, estimates that there are 5 million such vehicles in use worldwide.

Nanomaterials are a key to meeting most of these challenges, in part because their interfaces allow reactions to take place that would not occur in bulk materials of the same composition. In batteries, nanomaterials can increase the electrode/electrolyte contact area, thereby increasing the charge and discharge rates. They also decrease the path lengths that reactants have to travel, thereby increasing the power of the system.

To date, the best material developed for a vehicle battery, according to Frois and Yusheng Zhao of the University of Nevada at Las Vegas, is the so-called "iron phosphate"cell, in which both the anode and the cathode are made of nanosized particles. This $LiFePO_4/Li_4Ti_5O_{12}$ battery can be fully recharged in 10 minutes, and is safe and stable. The solid electrolyte leads to super-ionic conducting in this system. But there is still room for improvement, and researchers are investigating other cathode materials, such as $Li_7La_3Zr_2O_{12}$, and Si/C for high energy anodes. Performance might be further increased by the introduction of battery management systems in vehicles. Such systems would use sensors and actuators attached to a core CPU to improve diagnostics, ensure safety, and increase the performance of a battery pack.

General Motors already has a hydrogen powered vehicle, the Opel HydroGen4, on the market in Europe. It has a range of 320 km (220 miles) and a top speed of 100 mph. The compressed hydrogen fuel is carried in high pressure storage tanks. The hydrogen is fed to fuel cells, which react hydrogen and oxygen across a proton exchange membrane, to produce energy and water. A key materials challenge for fuel cells is reduction of the amount of the expensive element platinum used in the catalyst, and improvement of its durability, because it is sensitive to pollutants and carbon monoxide. Automobile company researchers have "platinum reduction roadmaps" in place that are designed to use less platinum in morphologies that increase the exposed platinum surface area available for catalytic activity. They are also developing catalyst regeneration protocols to reuse the same catalyst for longer periods.

Honda has its FCX fuel cell vehicle on the market already, and several other manufacturers have announced their intent to produce fuel cell vehicles by 2014. Germany and Japan have each announced that 1,000 hydrogen fueling stations will be installed in their countries in this decade. The U.S. Department of Energy has announced targets for 2015 of fuel cell vehicles with system efficiency of 60%, system durability of 5000 hours, and vehicle range of 500 km (310 miles).

Opel (GM) HydroGen4. *Opel GMBH.*

A car can store energy, so it can become part of a smart grid.

—Bernard Frois
CEA, France
2011 World Materials Summit, Vehicles

The panel had two main points for its Vision 2030: the de-carbonization of transportation, and "smart roads, smart cars, and smart networking." Other points in this vision include durability and long-term reliability of batteries; sustainability; economy; and market deployment of high efficiency cars.

Developments required to reach this Vision include

- High efficiency internal combustion engines to decrease fuel consumption
- High energy density and high power capacity batteries
- Fuel cells with cheap catalyzers and better membranes
- Reduced-weight vehicles, using composite materials
- Optimization of power management systems
- Sensors and real-time information
- IT networking

The panel **recommended** that the materials science community attempt to expand dialogue with policymakers and industry; develop a roadmap and update it every two years at the World Materials Summit; study specific issues related to buses and trucks (heavy duty vehicles); link with aircraft industrial needs for batteries and fuel cells; analyze materials needs for high speed trains; and develop new architectures in power electronics (powertrain management), and link these with intelligent technologies.

International Collaboration was also a major concern of the panel members. They suggested the development of international policies to facilitate scientific exchanges, develop an agreement on long term vision, share concepts and best practices, agree on codes and standards, and focus on technological research and technology transfer.

Regarding **Policy, Industry, Outreach and Education,** the panel suggested the development of national/central government policies, the establishment of regional/local policies, the involvement of industry at an early stage, the development of regulations and standards, the assessment of risks and liabilities, the offering of incentives, the enhancement of public awareness and involvement, and the education and training of the next generation of scientists and engineers.

They also warned of the following potential **Roadblocks:**

- Unbalanced competition, which slows information exchange while stunting competitive innovation
- Patents and IP protection, which prevent technology transfer in the absence of healthy market compensation
- Slow public acceptance, which may delay market deployment
- Lack of access to strategic materials (rare earth elements, Li, rubber, transition metals), which could hinder progress.

Honda FCX fuel cell. *Honda Motor Company.*

Green concept car.

Buildings

Buildings are among the largest users of energy in the world. Globally, buildings account for 30 to 40% of primary energy use, 57% of electricity demand, and 25 to 33% of greenhouse gas emissions. Residential energy use varies by region, with cooking accounting for the majority of energy used in India (approximately 70%), while in Europe cooking consumes only about 5%, but heating accounts for about 70%. A number of studies have concluded that retrofitting existing buildings to increase energy efficiency and requiring a high level of energy efficiency in new buildings is the most cost-effective way to reduce carbon emissions. Strategic materials solutions can help to reach this increased energy efficiency. But deciding what materials challenges to pursue is not easy, because "you can't put a building in a test tube," as Ron Judkoff of the National Renewable Energy Laboratory (NREL) said at the 2011 World Materials Summit.

You can, however, use sensors to measure the energy variables in a building, and then plug these values into advanced software packages to simulate energy flow and consumption. Such software can produce models to suggest the best energy use scenario for a particular building in a particular climate.

These models have revealed that, with currently available building technologies, a "neutral cost " point is reached at about 60% energy savings compared to a building that just meets code requirements. That is, constructing a building with 60% energy savings results in the same cash flow burden to the building's owner as a minimally code-compliant building. To go beyond the neutral cost point requires potentially expensive technological advances. Solar energy produced by photovoltaics could perhaps extend the energy savings to 80%. The region between 80 and 100% is a "technology gap" that scientists have the opportunity to fill.

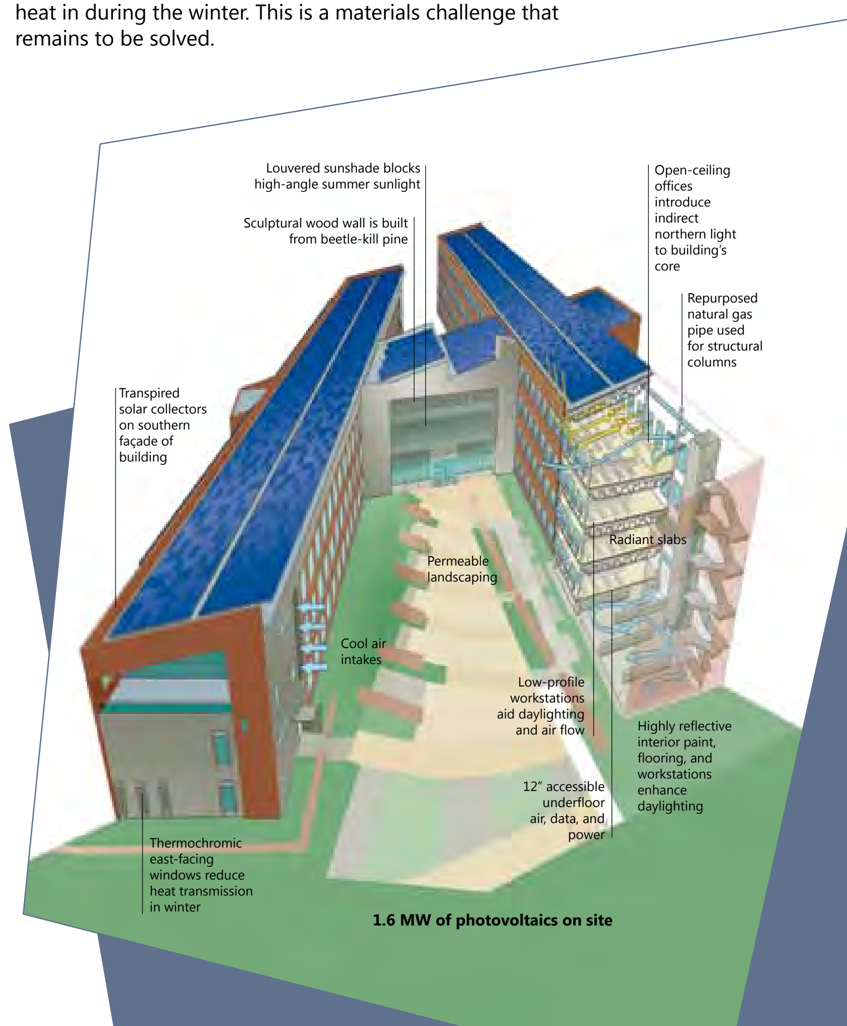
This gap could be addressed by developing materials for walls, roofs, and floors that have a higher thermal resistance, reported as R-values in the industry, and high moisture resistance. Insulation materials under high vacuum eliminate heat conduction and convection, leaving radiation as the only means of heat transport. Laboratory prototypes have achieved R-values up to seven times higher than the best rigid cellular insulating panel available today, but maintaining a high vacuum for the life of a building is difficult, as leaks are likely to occur.

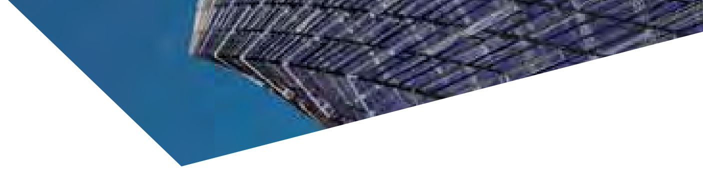
Phase-change materials that absorb heat during the day and release it at night by changing structure are also being investigated by materials researchers. The challenge is to minimize the volume change of the solid material undergoing a phase change to maintain its structural integrity in an enclosed space during many temperature cycles.

For windows, low-emissivity coatings, electrochromic materials, and high-thermal-resistance glazings are desirable. Commercially available electrochromic windows that can be controlled to lighten or darken are becoming more sophisticated, but they still require energy input to change the window's transparency level. Ideally, they would be able to simultaneously darken and reflect in the summer to keep rooms cool, and simultaneously darken and let heat in during the winter. This is a materials challenge that remains to be solved.

Buildings are some of the largest users of energy. There's a great opportunity to make materials decisions to increase energy efficiency.

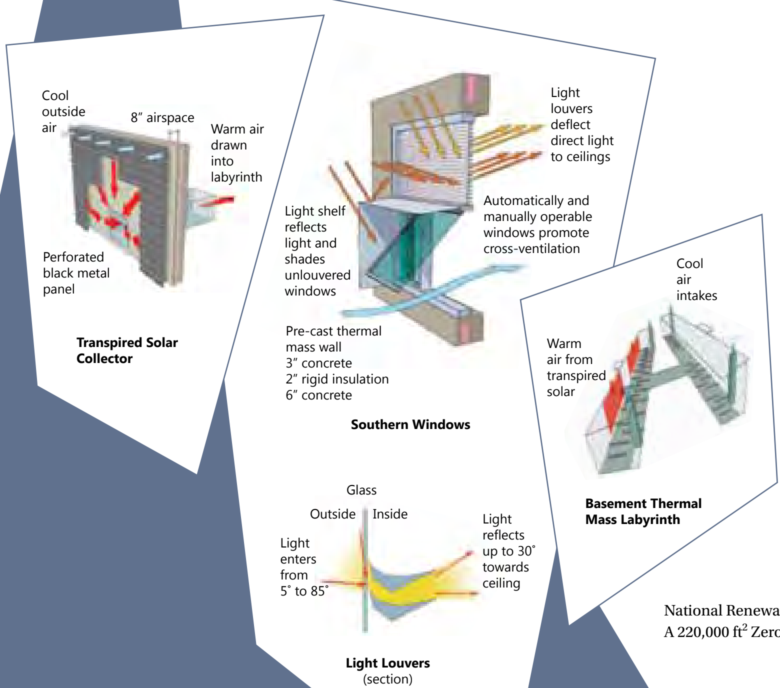
—Ron Judkoff
National Renewable Energy Laboratory
2011 World Materials Summit, Buildings/Lighting Panel





The panel on Buildings and Lighting emerged from their discussions with this Vision Statement: "Relationships with materials scientists must be strengthened among building scientists, building designers (architects), and the building materials industry, to achieve a 50% reduction in global energy consumptions in buildings by 2030. [This is also in alignment with AIA 2030 (American Inst. of Architects) and DoE stated goals.]" They also announced three major recommendations:

- Building scientists (which includes systems simulation specialists) must work together with materials scientists in alignment with industrial materials providers and integrators.
- Basic materials researchers should develop much greater understanding and appreciation for Life Cycle Assessment.
- Advances are needed in thermal exchange materials and advanced optical materials, but must be constrained by extremely low costs and high performance.



National Renewable Energy Laboratory (NREL) Research Support Facility (RSF)—
A 220,000 ft^2 Zero Energy Office Building in Golden, Colorado. *NREL*

Regarding research, the panel established the following priorities:

- to understand location-specific dynamics and location-dependent materials demands.
- to develop better whole systems-scale simulation and optimization tools with easy user interfaces.
- to expand research in phase-change materials.
- to develop cost-effective semiconductors for sensors, lighting, communications, and power electronics.
- to develop cost-effective materials for integrative sensors, microelectronics, energy harvesting, communications and controls.
- to expand thin-film research into meso-scale thickness range (200 nm–5 micron) and variable porosity (from compact to 50%) for heat exchange fins, ionic exchange membranes, photovoltaic thin films, electrochromic films.
- to increase efficiency of HVAC systems with novel heat exchange, working fluids, innovative dehumidification technologies, making use of low-grade thermal energy.
- to develop materials with controllable and variable surface optical properties to optimize the interface between the building and the environment.
- to develop adaptive vapor retarders (sometimes an impermeable humidity barrier, sometimes allowing moisture vapor permeability).
- to improve Indoor Environmental/Air Quality. Materials scientists will likely be called upon to develop materials for systems that remove/filter organic contaminants (volatile organic compounds), microorganisms, particulates, and inorganic molecular species from the indoors, and to develop new building materials that do not emit a concentrated hazard (e.g. aldehydes, particulates) in the first place.

Non-scientific issues that need to be addressed include:

- recognizing when intellectual property issues serve as barriers to collaboration and learning both regionally, nationally, and internationally.
- developing strengths/skills in Life Cycle Inventory for materials (database generation) and Life Cycle Assessment—both of which are critical to the building industry.
- developing building research testbeds in major housing types (most are large, multifamily structures), and factories, and in different climatic areas of China as international collaborations.
- accelerating the mutual understanding between Western researchers and Asian researchers by establishing professional society offices in China to encourage exchange of information. (Western researchers do not typically have a strong familiarity with the Chinese built environment and social considerations.) Also consider matching funds with China to increase research scientist visiting fellowships to China.

Water

Although Earth has an abundance of water, it is not evenly distributed geographically. Even where fresh water is readily available, competition for its use as drinking water or for industrial or agricultural processes can lead to conflicts. And because most of the planet's water is oceanic saltwater, desalination is required before it can be used for many purposes. Clearly, finding sustainable means to provide water for its numerous applications is a high priority.

"Water and energy are interdependent," said David Cahill of the University of Illinois at Urbana-Champaign at the 2011 World Materials Summit. Water is used in large volumes as a coolant in many industrial processes, including power plants. The recent increase in hydraulic fracturing (or "fracking") activity to break up tight shale formations and release natural gas in areas such as the Marcellus Shale region in the eastern United States, has introduced another competitor for water. Hydraulic fracturing forces large volumes of water (mixed with other chemicals) at high pressure into shale formations, creating cracks through which the natural gas can escape. The resulting wastewater must undergo extensive purification before it can be used again for another purpose.

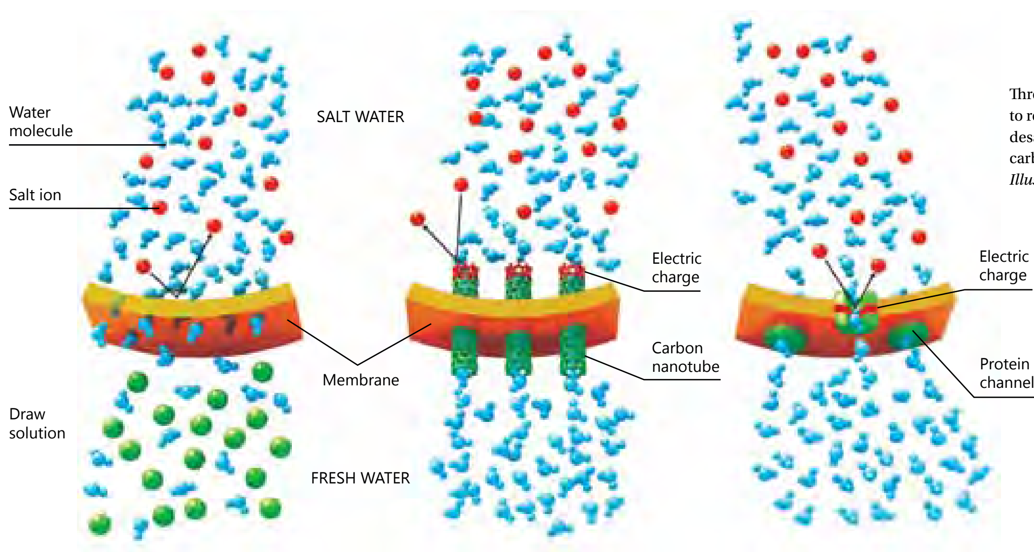
Materials science can help to optimize water use by developing low-cost solutions for returning "impaired" water to the useable water supply, by removing micropollutants and disinfecting it without creating dangerous byproducts. The process of reverse osmosis has long been used for desalination, but it does a poor job of rejecting neutral molecular contaminants, and is subject to biological fouling. Furthermore, a vast area of reverse osmosis membrane—about the size of a football field (approximately 5,350 m^2)—would be needed to purify 1 million gallons of water per day. Much research is being done on advanced membranes that might solve these problems with the reverse osmosis process.

One promising material is a 100-nm thick polyamide on a porous polysulfone support. The use of such membranes to trap contaminants rather than disinfecting them using toxic chemicals like chlorine could aid in sustainability by reducing pollutants in the environment. Also, "robust sensing of contaminants in real time could be a game changer," Cahill said. Materials he calls "DNAzymes" for highly selective sensing of heavy metals might be the answer to this challenge.

"Water purification is an incredibly important problem that is underserved by the scientific community," Cahill concluded.

Water and energy are interdependent.

—David Cahill
University of Illinois at Urbana-Champaign
2011 World Materials Summit, Water Panel



Three technologies competing to reduce the energy required for desalination—forward osmosis, carbon nanotubes, and biomimetics. *Illustration by Bryan Christie.*

The Water Panel presented these long term visions and goals:

- Increase water supplies where and when they are needed through efficient purification of impaired water. Sources of water will be greatly expanded. Seawater, brackish groundwater, and water contaminated by pathogens and hydrocarbons can be cost-effectively purified. Recycling of waste water will also play a critical role in increasing water supplies.
- Detect and selectively remove low levels of toxic contaminants at low cost. Extremely dilute but highly toxic inorganic and organic contaminants are a particularly challenging problem in water purification. New methods will enable the detection and destruction of such contaminants rapidly and at low cost.
- Disinfect water without producing toxic by-products. Traditional methods of disinfection are based on homogeneous chemistry using chlorine-containing compounds. A vision for the future is to replace chlorine-based disinfection with processes that effectively disinfect microbial and viral pathogens without generating toxicity.
- Develop low-cost, robust systems with minimal energy and chemical inputs that can be deployed world-wide.

Lifestraw® portable water filter can be carried around for easy access to safe and clean drinking water. *Vestergaard Frandsen.*

The panel also identified several Materials Research Needs:

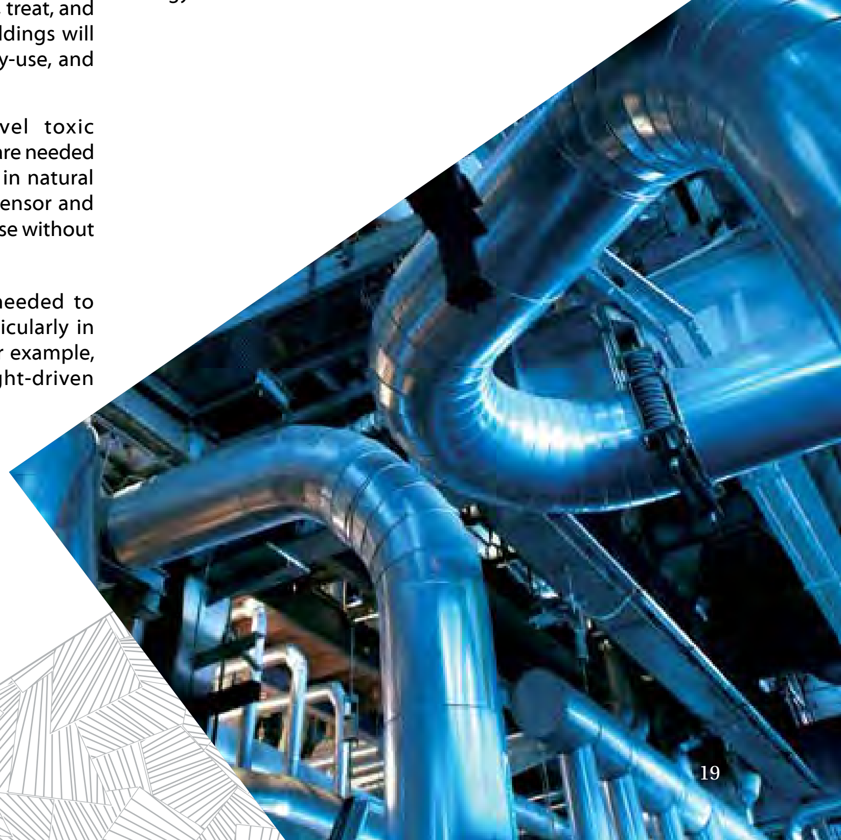
- Multi-functional materials. Significant reductions in cost and complexity can be achieved by developing materials with greater functionality. For example, membranes with the ability to self-clean or membranes that can both separate and disinfect could transform membrane processes. Materials that combine functions of concentration—e.g., selective adsorption or ion exchange—and catalytic destruction will enable more efficient decontamination.
- Membranes. Membranes for seawater desalination are a relatively mature materials technology. Expanded use of membrane processes will face, however, a wider variability in the composition and quantities of water contaminants. Science and engineering approaches that will enable the rapid development and deployment of new membranes that are optimized for specific applications at both large and small scales need to be developed. Membrane processes that purify, treat, and recycle water at the scale of individual buildings will produce significant savings in water, energy-use, and safety.
- Detection and destruction of low-level toxic contaminants. Sensor materials and systems are needed that are sensitive, selective, and long-lived in natural water and in waste streams. Autonomous sensor and purification systems will enable rapid response without intervention by operators.
- Disinfection. Advances in materials are needed to improve the safety of water supplies, particularly in non-industrialized regions of the world. For example, materials are needed that enable sunlight-driven disinfection.

International Cooperation

As with energy, water is an international problem. World-wide energy use is growing; water use will grow too. Water, however, is almost unique among natural resources by its location at and crossing national boundaries. As a consequence, water will increasingly become a cause of conflict between nations, unless institutions and mechanisms are developed for greater international cooperation in these matters.

Outreach

Public awareness is needed of the value of water and the fact that clean sources of water need to be protected. Public understanding of the health and safety of water sources, and the risks associated with various water contaminants, is limited. The message needs to get out that water recycling is a safe method of increasing water supplies and also has many benefits to the environment in reducing the use of energy and chemicals.



Policy and Education

Numerous governmental energy and sustainability policies were presented during the 2011 World Materials Summit, some of them similar among nations and others different, reflecting both the commonality and diversity of energy needs across the world. While Germany is getting out of the nuclear energy business by 2022, France is staying in, possibly because they are already so highly invested in the technology. Rapidly developing countries such as India and China need so much energy to meet their emerging lifestyles that they cannot afford to rule out nuclear energy. In the United States, while signs of renewed interest in nuclear technology are appearing, accidents such as the one at Fukushima Daiichi in Japan may slow down the pace of public acceptance. Independent of public comfort, economics is a major factor in deploying nuclear power while cheap fossil fuel alternatives, such as natural gas, are plentiful.

Renewable energy sources are drawing the most interest and show the most room for growth, though they also face policy challenges that they must overcome. China's highly subsidized photovoltaics industry is making them the current winner in production and sales of solar cells, while the lack of such governmental subsidies elsewhere makes competition difficult. Wind energy is making great inroads into the renewable energy market and research is needed to minimize the environmental impact giant windmills cause to animal populations, and the impact on mining regions where rare earth elements are extracted for magnets. While scientists and engineers have made great strides in the area of "clean coal," much more needs to be done to ensure that coal can be in the energy mix in the coming decades without jeopardizing environmental concerns. Policymakers must work out the conflicts in these instances.

Perhaps the greatest need for new policies is in the area of international cooperation in the development and sharing of renewable energy technologies. Many of the expert panels at the 2011 World Materials Summit cited the need for worldwide standards and testing laboratories to ensure uniform performance ratings for comparison of technologies. The panels have also called for international funding of research into energy and sustainability issues that affect no single country but the whole planet. Can international policies be developed and signed to eliminate national boundaries in such vital issues? Developing ways to fund international teams is a key to answering this question.

The answer relies to some degree on education of our leaders and the general public on the true scientific issues that underlie these policies. Besides educating the next generation of scientists and engineers at our universities, scientists must actively seek opportunities to educate the public on topics of energy and sustainability—speaking at public forums to give the general population enough information to guide their decisions in elections and policy discussions. They must also engage our political leaders and communicate the importance of research and development in solving some of the world's greatest problems. Verifiable scientific data minus the hype is needed by these officials to make the best policy decisions in cases of energy and sustainability; we owe them that much as they try to do their difficult jobs in this ever more complex world.

We're beginning to realize that our nationalistic views and efforts are not sufficient. A world effort is necessary.

Dave Ginley
National Renewable Energy Laboratory
2011 World Materials Summit, Policy and Education Panel

The panel observed that materials scientists need to be better spokespersons for the public; that policies of governments are a result of informed citizens and the general public; and that there is a natural tension and the need for balance between competition and cooperation. Based on these observations, the panel chose two overarching goals: educating materials scientists to be better spokespersons with the public, and aligning international cooperation.

The panel divided “Educating Materials Scientists to Be Better Spokespersons with the Public” into three sections:

- System Level Thinking, which involves developing increased understanding over time; recognizing differences for each country; seeking federal grants for public outreach; and developing education kits to survey and share information across countries. Other challenges are building a community that is better informed by developing workshops at major meetings, and including other groups, e.g., social, economic, and environmental, to interact with materials science students.

- Outlining Challenges beyond Scientific Research, which involves showing a linkage of research to innovation; shifting the paradigm of professional societies to include research to innovation in their meetings; recognizing the need for different vocabulary/thinking when speaking to communities that have a stake in sustainable issues; and mapping world needs in energy with materials science.

- Highlighting Materials Impact on Our Daily Lives, which includes educating the public using current examples; balancing applications with the need for and the importance of research programs; looking for experiences from each country that can be shared; involving industry, government agencies, and universities; analyzing economic impact on GDP of materials research and innovation; and creating interaction with others for better understanding.

The “Aligning International Cooperation” goal was subdivided into two sections.

- Recent efforts specific to energy in Europe and the United States are very timely and should be maximized as soon as possible. For Horizon 2020, this will require identifying joint S&T opportunities, e.g., battery standards and establishing collaborative efforts; looking beyond science-only opportunities for joint work, e.g., social economic factors; selecting common energy goals; searching for other countries and regions beyond the European Union and the United States that have plans in common; and looking for opportunities to include developing countries in these areas of high priority. In terms of manufacturing science, the panelists noted that attention to manufacturing is currently ongoing in all countries where front-end science can make a big impact on industry. To enhance this effort, researchers need to focus on energy examples that are specific to the science of manufacturing.

- Recycling. The panel called for implementing a cradle-to-grave design and mindset; identifying and anticipating widespread implementation of energy technologies; developing a mentality for recycling, e.g., photovoltaics, batteries, critical materials; developing standards; proposing and helping to pass legislation; developing practical consumer education methods; eliminate the negative impact on developing nations; and thinking about long-term impact and economics.

2011 World Materials Summit

STUDENT CONGRESS

L'Enfant Plaza Hotel | Washington, DC | October 9-12, 2011

Energy outlook—A perspective from the new generation of materials researchers

As part of the October 2011 World Materials Summit and Student Congress—an international gathering of present and future leaders of science, technology, and policy—we participated in discussions of global challenges on energy, sustainability, and water. We began the Student Congress with a tour of the U.S. Capitol building. Atop this magnificent structure sits the bronze Statue of Freedom. She stands on an iron globe inscribed with the phrase *E pluribus unum*.

These words defined the Congress, comprised of students and postdoctoral fellows from many parts of the world, charged with contributing to a single declaration on the pressing concerns of energy. This declaration is to be presented to the materials research community and the public in general.

The magnitude of the task necessitates coordination among nations, and nations do not always agree. Raw materials, monetary resources, and technological capability are not distributed evenly. Thus some participants argued strongly for renewables such as wind and solar, while others pointed to the scalability of nuclear and coal. Given the diverse set of opinions and realities we represented, no final consensus was reached, nor was it expected. Everyone understood that these regional and national differences do not preclude us from working together for a more sustainable world.

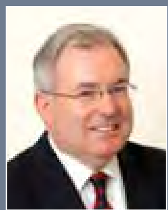
In the end, our group of 45 participants in the Student Congress reaffirmed that as scientists, we are obliged to sensitize and inform ourselves, the public, and the people who represent us in government. When the Summit reconvenes in Paris in 2013 and judges what we managed to accomplish, perhaps its participants can look to *La dame de fer* for further inspiration and guidance.

Isaac Tamblyn (Canada), Ivana Aguiar (Uruguay), Ratna K. Annabattula (Germany), Gusphyl Justin (USA), Kayvan Rafiee (USA), A. Rios-Flores (Mexico), Antonio Vicente (Portugal), Jenny G. Vitillo (Italy), and Deniz Wong (Taiwan)

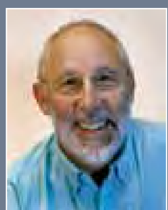
MRS Bulletin, Energy Quarterly, December 2011.

www.mrs.org/2011wms

2011 WMS Chairs

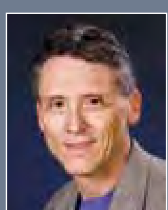


Gabriel Crean



David Ginley

Yafang Han



Alan Hurd

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