REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
5/23/12

2. REPORT TYPE
FINAL

3. DATES COVERED *(From - To)*
1/3/2011-12/30/11

4. TITLE AND SUBTITLE
World Materials Summit

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-11-1-0231

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Tim Palucka, Science News Editor/MRS
Betsy Fleischer, Ph.D., Principal Development Editor/MRS

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Materials Research Society
506 Keystone Dr
Warrendale PA 15086-7537

8. PERFORMING ORGANIZATION REPORT NUMBER
2011 WMS:Final

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ONR
230 S Dearborn Rm 380
Chicago IL 60604-1595

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

No restriction

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The 2011 World Materials Summit brought together global scientific experts and policymakers to continue the dialogue in the U.S. Capitol on the role of materials science in energy and the environment. It focused on the critical links among materials research, energy, and sustainable development on a global scale. Abundant clean energy supplies and reliable energy storage systems are needed to address many critical societal issues in development and developed countries. On a broader scale, access to energy is a key factor in determining society's quality of life and economic prosperity. Energy technologies can impact day-to-day life in developing countries. Clean, renewable energy, in particular solar technologies, holds much promise for rural communities. Much work is being conducted to develop de-centralized, self-contained energy generation (or conversion), storage and use for rural regions of the world. Innovations reducing the cost of production, increasing device efficiency and improving device sustainability should enhance the spread of their impact in developing countries. Materials research continues to be at the forefront of new energy technologies. This Summit helped to stimulate the materials science and broader community to understand the many facets of the energy challenges facing the world in the next decades, to see the opportunities for materials science to help meet those challenges, to see the interconnected nature of the problems, and to provide a forum for scientifically sound input to public policy.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: N/A			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	None	160	Donna J. Gillespie
					19b. TELEPHONE NUMBER *(include area code)* 724-779-2732

cc: Defense Technical Information Center

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

20120531030

The third in a series of World Materials Summits, this one held in Washington, D.C., from October 9-12, 2011, came with major addition: a Student Congress featuring 45 graduate or post-doctoral scientists from 18 countries around the world. These young researchers added a dose of fresh enthusiasm, ideas, and energy to the proceedings, supplementing the experience and knowledge supplied by the more senior attendees, who provided expert presentations and guidance to fuel the discussions that were the focus of the gathering: http://www.mrs.org/2011wms/

The 2011 World Materials Summit, like the previous summits held in Lisbon (2007) and China (2009), was a cooperative effort of the MRS, the European MRS, and China MRS. The meeting was chaired by Gabriel Crean of the Commissariat a l' energie atomique et aux energies alternatives (CEA) in Europe, David Ginley of the National Renewable Energy Lab in the United States, Yafang Han of the Beijing Institute of Aeronautical Materials in China, and Alan Hurd of Los Alamos National Laboratory in the United States. It was funded in part by National Science Foundation Division of Materials Research; the United States Department of Energy, Office of Basic Energy Science; the Office of Naval Research, Naval Materials Division; Aldrich® Materials Science; Dow; American Elements; and the Materials Science and Engineering Expert Committee (MatSEEC).

The first day of the summit featured nine tutorial presentations on energy, sustainability, and water supply issues, to bring the students up to date on current thinking in these areas. The chairs spoke briefly about the purpose of the summit and what they hoped the outcomes would be. The primary product would be a World Materials Summit Declaration summarizing the main challenges and potential solutions identified by the summit's participants.

Alan Hurd noted that "the Student Congress grew out of a desire to find some way for early-career scientists to have a voice" in the ever-important dialogue regarding materials, energy, and sustainability. Lynn Orr of Stanford University followed with a broad talk on "Global Energy and the Environment," in which he stated, "energy is the primary way we interact with global systems that we count on—air, food, and water." His talk included discussions of evidence for global climate change in greenhouse gas concentrations, both in the atmosphere and in the oceans, which have become more acidic through uptake of carbon dioxide; ice sheets, which are rapidly thinning; and the rise in sea level, which is exceeding the rate predicted by the IPCC. Global supercomputer simulations are helping to track and predict global climate change. "It's a question of when, not whether," global climate change will begin to have a major impact on our lives, Orr said.

"Renewable Energy Generation" was the subject of the talk by Ryne Raffaelle of the Rochester Institute of Technology. Renewable energy comes from natural resources that are naturally replenished, according to Raffaelle. "For true sustainability," he said, "a solution must be socially acceptable, environmentally friendly, and economically viable." Currently, 16% of global energy comes from renewable resources, but that's mostly from burning wood. For viable wind power, we need lighter, stronger, stiffer materials with better coatings to protect them from the environment. The production of photovoltaic devices for solar cells grew by greater than 100% in 2010, Raffaelle said, with 80% of production in Asia and 80% of deployment in Europe. He also talked about solar concentrator systems, Li-ion batteries, and hydrogen as fuel.

Bernard Frois of CEA in Europe spoke about "Batteries, fuels cells, and electrical vehicles." "Our biggest challenge is the de-carbonization of transportation," he said. To achieve this, the CEA has a goal of controlling the whole chain of the vehicle power process, including electrode materials, electrochemical cells, battery packs, battery management systems, intelligent charging, and testis in labs and vehicle fleets. Frois said that they already have the "best material ever for a battery" in $LiFePO_4/Li_4TiSO_{12}$ (LFP/LTO), which is stable and safe, and can fully charge in 10 minutes. Following up on the same theme, Yusheng Zhao on the University of Nevada—Las Vegas said that "hybridization and electric drive is the future of transportation." He agreed with Frois that LFP is the best cathode ever developed for a battery, but noted that a solid electrolyte is necessary to achieve the desired super-ionic conducting regime.

The National Renewable Energy Laboratory Research Support Facility is a 220,000 square-foot, zero-energy office building, according to Ron Judkoff of NREL. He noted that buildings are among the largest consumers of energy, and thus present a great opportunity for materials scientists to develop new building materials with higher energy efficiencies. "But 'building science' is an oxymoron," Judkoff said. "You can't put a building in a test tube." Instead, they combine measurement and simulation to understand cause and effect related to building energy uses. One of the challenges in building design is that there are almost too many energy efficiency devices to choose from, according to Judkoff. These include photovoltaic roofing shingles; compressionless cooling; dessicant-evaporative air conditioning, solar thermal technologies to heat water; electrochromic windows; and phase-change materials that absorb or release heat as their structure changes.

Frances Houle of the Lawrence Berkeley National Laboratory spoke next about "Energy Critical Elements," focusing on the well-known shortage of rare earth (RE) elements. "Little cars are reservoirs of Res," she said, noting that the Toyato Prius has 10-11 kg of Res, mostly lanthanum. REs are also used in magnets, catalysts, electronics, glass, ceramics, and metal alloys. Production issues that Houle listed include the poorly understood geology of the elements; their low concentrations in the earth; the unfamiliar metallurgy of co-produced metal mixtures; the waste lost in uneconomical mine tailings; and the radioactive actinides that are usually contained in the ores. South China clay contains all 17 RE elements, putting China in the best position to control this market in the coming years. Houle contended that we need to differentiate temporary fluctuations in supply from long term trends, and that we need a sustained commitment in materials science research to find substitutes for these elements.

Carbon dioxide might be more than just a greenhouse gas, according to Jacques Amouroux of XXXXX. In his talk "CO_2 as a raw material for an industrial revolution," Amouroux proposed using the billions of tons of CO_2 emitted each year as a reactant to produce fuels. This could include reacting it with hydrogen to form methane or methanol, or using it in the Fischer-Tropsch process to produce synfuel. The hydrogen could come from the electrolysis, photosynthesis, or photolysis of water. Combining coal, carbon capture and sequestration, hydrogen, and CH_4 could result in liquid hydrocarbon fuels costing $40 to $S0 a barrel, Amouroux speculated.

David Cahill of the University of WaterCAMPWS, an NSF-funded project for the purification of water, took an interesting angle on the sustainable use of water for cooling in energy processes in his talk "The challenge of water: A tutorial on thermodynamics." The interconnection comes from the fact that "for every watt of power generated, we have to sink thermal watts," Cahill said. The most efficient way of doing this is with water, which has a heat of evaporation of 2 GJ/m3. This means that we must evaporate 0.5m3 of water per second for a 1 GW nuclear power plant. But this cooling water is in competition with the water we drink and the water we use in agriculture to grow food. Cahill discussed purification of the water used in industrial cooling for these other means, and also the prospect of desalinating salt water for our water needs using semi-permeable membranes and reverse osmosis. There is an incorrect perception out there, he said, that desalination requires a huge amount of energy.

Harry Kroto, the 1996 Nobel Laureate in Chemistry for the discovery of buckminsterfullerenes, finished the first day with a wide ranging, often inspiring and humorous talk on the "Challenges of energy and policy." He showed the students a photo of Einstein in his later years, and said that this was not the man who discovered relativity. Switching to a photo of a young Einstein working as a patent clerk in Switzerland, he said that this was the man who made that significant discovery. His point was to inspire the students that great work was possible while they were young. In his own career, Kroto was a spectroscopist who was interested in synthesizing C=S and C=P molecules. Working with David Walton, he used a Cu catalyst that produced a chain 32 carbons long, which eventually led to the discovery of the C60 molecule. "I was investigating a little problem that interested me," Kroto said. "The prizes come later if you're lucky."

The second day of the World Materials Summit was dedicated to keynote addresses by prominent officials of the sponsoring countries, and plenary talks delivered to the newly arrived Summit delegates, as well as the Student Congress members.

Steven Koonin, Undersecretary for Science at the U.S. Department of Energy summarized DOE's First Quadrennial Technology Review Report, which was intended to provide a systematic method to review their R&D portfolio. Three themes emerged from this analysis: (1) We need to better understand our present energy system, (2) We need to know what technologies are available, how long they take, how much they cost, and who can do it most efficiently, and (3) We need to realize that science is by and large the easiest part—the "softer stuff" in the middle of the development process is harder, according to Koonin. Doe is currently exploring six paths. The three "transport" paths are deploying alternative hydrocarbon fuels, electrifying the vehicle fleet, and increasing vehicle efficiency. The three "stationary" paths are to deploy clean energy, to modernize the grid, and increase building and industrial efficiency.

Summit Chair Gabriel Crean, Vice President of Technology for CEA, France, gave the audience "A European Perspective" on energy and sustainability. The European Commission has established "Key Enabling Technologies (KETs)" on which to focus scientific research. In materials science, the six KETs are advanced materials, nanotechnology, micro- and nano-electronics, photonics, biotechnology, and advanced manufacturing. "KETs are essential to the development and manufacture of advanced products," Crean said, "and they are strategic all along the value chain." He looked at the disparity between patents issued and manufacturing share by geographical region for three technologies (Li-ion batteries, bio-ethanol, and photovoltaics), and concluded that "while many people say the world is flat, it is definitely not level." The quote was mainly referring to the fact that China had eight companies in the top 10 in the manufacture of photovoltaics in 2010, Europe had one, and the U.S. had one. Crean attributed this non-level distribution of market share to China's heavily government-subsidized photovoltaics industry. "Twenty-first century Europe requires a new innovation game plan that is cognizant of the 'real' international landscape," Crean concluded.

Dujin Wang of China spoke not of any governmental policy initiatives, but of the more technical aspect of CO2 as a feedstock for polymers. The most studied polymer in this field, according to Wang, is poly(propylene carbonate) (PPC). PPC is transparent, biodegradable, and a good oxygen barrier, but it has a low glass transition temperature. The catalyst used for manufacturing PPC must have high activity and good selectivity for PPC over PC. Lately they have been investigating rare earth ternary (RET) coordination catalyst made of Zn Et, polyol, and a rare earth complex. The two routes of synthesis they are examining include ball-milling the RET with γ-Al2O3 support, which yields an activity of 36%, and combining equimolar amounts of RET with Zinc-glutarate, which increases the activity to 54% and reduces the cost by 50%. The PPC will be used as film for packaging applications.

Sergio Alcocer, Undersecretary for Energy Planning and Technology Development for Mexico, gave a broad overview of his country's energy sector. Under the Ministry of Energy there are two government-owned companies—PEMEX and CFE—three national energy research institutes, and four commissions. Alcocer reported some turmoil in Mexico over decisions to relax rules governing state owned companies to increase investment capabilities. With this reform Mexico will be able to produce 3,307 thousands of barrels of oil per day by 2024; without reform, this will be 2,200 thousands of barrels per day. Eighty percent of their exported oil goes to the U.S. Regarding electricity in Mexico, 70% is generated by combustion of fossil fuels, 18% by large hydropower generators, 2.2% by nuclear power plants, 1.6% by geothermal (the largest geothermal plant in the world, Alcocer said), and 1% by wind turbines. Mexico has a potential for 11 GW of renewable energy, but currently only 520 MW is being realized. At this latitude, solar has a large potential of 5kWh/m2 per day on average. The 2012 target for geothermal power is 891 MW; for wind, 2,050 MW. To encourage efficient energy usage, Mexico has established a Sustainable Light Program, whereby the government will supply 45.8 million CFL bulbs to replace incandescent bulbs on a free and voluntary basis. They also have an appliance replacement program that helps low income families replace old refrigerators and air conditioners with more efficient ones.

The Plenary Session followed the keynote talks in the afternoon. Harry Kroto, Lynn Orr, and David Cahill gave slightly revised versions of the tutorial talks they presented on the first day of the summit.

George Crabtree of Argonne National Laboratory spoke on "Materials challenges in Renewable Energy." "Complex, high-tech materials and chemistry are both the driver and the bottleneck for raising the performance and lowering the cost of renewable energy," he stated. Crabtree gave a historical overview of renewable energy technologies, which he said started with NASA's requirements for solar-powered devices in space in the 1960s. He noted that with traditional energy sources, the most important "material" is the fuel that is burned to turn heat into work. In the sustainable regime, the most important "material" is unused energy flow, he said. "Don't use combustion, use direct conversion." The conversion of solar energy directly to electricity using photovoltaics, and the conversion of biomaterials to fuels using catalyzed chemical processes were two examples he gave. He also talked about innovations in wind power technology, including "urban wind" technology that takes advantage of wind funneled between buildings. "You just have to put the windmill in the right spot," Crabtree said. Superconducting wind turbines provide a factor of two increase in power for each unit increase in weight, he noted.

"Bringing Photovoltaic Energy Conversion to the Terawatt level" was the subject of the talk by Patrick Bressler of Fraunhofer-Gesellschaft, Institute for Solar Energy Systems (ISE).German public opinion is very strong against nuclear energy, because the risk is not considered acceptable, according to Bressler. The government announced a policy of shutting down all nuclear power reactors by 2022, and replacing most of the lost power with renewable resources. The photovoltaics market is forecasted to be 110 GW in Germany by 2020, which Bressler said is a "huge growth rate." To meet this prospective demand, ISE is investigating several enhancements to PVs. One is making laser-fired contacts, which creates bumps on the backplane of a thin monocrystalline silicon solar cell. This increases the efficiency through a light trapping mechanism. They are also looking at laser chemical processing of solar cells.

Duan Weng of Tsinghua University spoke next on "Life cycle assessment as a component of materials science and engineering for a sustainable world. He emphasized "environmentally conscious materials" or "ecomaterials," which he said has a very specific meaning in Japan in China, but not in the rest of the world. "All materials and processes have environmental impacts," Bressler said. Even solar cells, which are green during operation, consume a lot of energy during their manufacture. Also, Pb-free ecomaterials often have toxic bismuth inside, because bismuth typically coexists with lead in ores. "Environmental assessment is missing in materials science and engineering," Bressler said, and life cycle assessment is the answer. The Chinese Energy Conservation and Emission Reduction (ECER) policy is in place, and has already analyzed more than 300 unit processes.

Paul Waide, Director of European Energy Practice at Navigant Consulting, addressed the challenges of the "Electricity Grid." In terms of materials, he sees "armchair quantum wires," which are high-temperature superconducting cables, as an opportunity to make transformers with efficiencies as high as 99.3%. Some of the main problems of today's grid is that electricity transfer is one way; transmission and distribution losses are as high as 15%; and metering is not very sophisticated, which leaves consumers confused about the costs of electricity. The solution will be a smart grid that uses digital technology to monitor and manage the generation and transmission of electricity from ALL sources (traditional and renewable) in order to meet the varying electrical demands of end users as efficiently as possible, according to Waide.

Jerry Gibbs of U.S. Doe Vehicle Technologies emphasized that oil is predominantly a transportation energy problem in his talk on "Future vehicles and energy." Reduction of oil consumption will depend on alternative fuels and electrification of vehicles; hybridization; increase in the efficiency of internal combustion engines; and light weighting of vehicles. A 10% mass reduction in an electric vehicle will result in a 10% increase in driving distance, Gibbs said. He believes that internal combustion engines with 60% efficiency may be possible in the future.

"Resource availability: Characterizing risk and identifying research opportunities" was the title of the talk delivered by Randolph Kirchain of MIT. "The materials community should be aware of risks associated with resource availability," he said. This involves measuring a new property: availability risk. Limited availability of resources can impact new materials technologies. When the cost of a resource skyrockets due to temporary scarcity, price changes can be temporary, but the *effects* on a manufacturing company can be permanent, he said. In these cases, some substitute materials are not replaced when the scarce element becomes available again. We can influence the resilience of materials systems by recycling, substitution, and increasing the efficiency with which we use them.

V.S. Arunachalam of the Center for Study of Science, Technology and Policy dealt with the subject of "Nuclear power: perceptions, performance, and promises." "Why does nuclear power have such a bad name?" he asked. "Is it a deal with the devil?" Arunchalam believes there is a future for nuclear power, despite the radiation fears, and the safety and security concerns. Not one percent of the people involved in the Fukushima accident in Japan died, and only 6,000 people had to move away, he said. The Chernobyl accident was due to a hydrogen explosion that could now be avoided by using different materials. The main concern he has is with nuclear proliferation, because "the same material needed for the production of electricity is also used in the production of atomic bombs." Four-hundred thirty-two nuclear plants generate 366 GW of electricity worldwide, with the majority of the nuclear reactors being light water reactors and boiling water reactors. This amounts to 13.5% of current global power generation needs. "What if we build no new reactors, and 150 existing reactors age by 2030?" he asked. It would be difficult to replace the lost electricity capacity with other energy sources. Arunchalam believes this will not have to happen because Generation 4 nuclear reactors, including fast breeder reactors and supercritical water-cooled reactors, will be much safer. (A fast breeder reactor was scheduled to go critical in India a few months after this talk.) Advanced heavy water reactors have no pumps that could fail, and a negative void coefficient. Zirconium rods generated hydrogen by reacting with steam at Fukishima and Chernobyl, leading to hydrogen explosions, not meltdowns; replacing zirconium with a substitute element could remove this risk. ""We must learn to live with complex systems," Arunchalam concluded.

William Brinkman, Director of the DOE Office of Science, spoke on "Advances in Materials Sciences." Doe's research focuses on synthesizing new materials, characterizing them, measuring and analyzing them, and creating theories to develop even newer materials, he said. Petaflop supercomputers capable of performing 1015 operations per second have made it possible to do a 48-million-atom simulation of cracking in pure Ni versus cracking in a sample with sulfur in the Ni grain boundaries. These supercomputers can help with the Materials Genome Initiative, for instance by finding all compounds that can be made out of two metals plus oxygen. "Simulations are giving us new materials to investigate," Brinkman said. "We hope to be able to go from the microscale to the mesoscale to the macroscale" in terms of materials simulations. The next step is the exascale (1018 operations per second) , but this comes with challenges, Brinkman noted. An exascale computer needs its own small power plant with 100 MW capacity, for one thing. Secondly, the smaller you shrink electronic devices, the more errors such a device will generate. We have to learn how to handle these errors. Besides supercomputers, DOE is working with other novel characterization systems, such as free electron lasers in the x-ray region of the spectrum, which can allow femtosecond x-ray protein nanocrystallography. "A biological liquid droplet is destroyed by the laser, but you get its diffraction pattern before it is destroyed," Brinkman said. Other advances include the LINAC coherent light source expansion, which is making wavelengths shorter the 2 angstroms possible; improvements in angle-resolved photoemission that allows single-photon-in/single-electron-out operation; and the ability to watch phase changes in real time on a surface with x-ray speckle imaging. "We can see the surface atoms in motion," Brinkman said.

The third and fourth days of the Summit were occupied with panel sessions, each discussing one aspect of materials for energy and sustainability. The expert delegates split into nine groups covering the smart grid; vehicles; resources; nuclear energy; buildings and lighting; energy fuels; water; renewables; and policy and education. Some highlights of the panel reports to the Summit as a whole:

- The smart grid panel said that the key materials challenge was in developing new energy storage materials
- The vehicles panel cited the "decarbonization of transport" and "smart roads, smart cars, and smart networking" as keys to sustainability in this sector'
- The resources panel noted that a "lack of understanding about mining ores containing small amounts of rare elements" and a further "lack of systematic knowledge about appropriate methods for recycling critical elements and finding substitutes for them" need to be addressed.
- The nuclear energy panel considered the critical question to be "are nations collectively (or individually) ready to adopt measures to control greenhouse gases?"
- The buildings and lighting group contended that "a lot of the available technology to improve the energy efficiency of buildings is not being used." They also cited the importance of life cycle analysis: "Materials researchers need to understand the costs of building materials across their entire life cycle."
- The panel on energy fuels focused on biomaterials as the feedstock for fuels, specifically lipids and lignocelluloses from algae or other sources, and the need for "enzymes to take apart cellulose in an intelligent way."
- The water panel said that multifunctional materials, "membranes that both separate and disinfect," are needed, as well as a more complete understanding of the mechanisms of oxidation and disinfection by photocatalysts.
- The renewables group made the bold recommendation that MRS should set up a competition to identify the best organic-photovoltaic research groups around the world and "connect them via an international coordination framework."
- The policy and education panel noted that in order for materials scientists to be better spokespersons for public education, they need to be "better informed, not just active."

The Student Congress divided into five panels to discuss the overall materials/energy/sustainability situation; markets and economics; water; education and international collaboration; and outreach, advocacy, and policy. Each panel contained students from different countries to give a global viewpoint to the issues under consideration. The exchanges were lively, as students sought to explain what conditions were like in their own countries, in order to argue why a certain technological solution would or would not work there. These panels reported their conclusions to the Summit as a whole on the fourth day, and their recommendations were included in the Summit Declaration. The general panel determined that the most important role of materials scientists was to "provide unbiased reporting and analysis of energy technologies based on standardized sustainability metrics." The markets and economics panel called for "multinational funding of research to improve clean energy and water technologies globally." The education panel urged educators to "create adaptive curricula to address sustainability and interdisciplinary studies." Finally, the outreach group noted that "students have a responsibility to be advocates, leading by example in their lifestyles and research."

Chair Dave Ginley led a discussion on the inclusion of key recommendations in the World Materials Summit Declaration. After a break, he presented a draft of the declaration to the assembled delegates, and it was approved unanimously. The text of 2011 World Materials Summit Declaration follows on the next page.

The LinkedIn Group on Materials for Energy and Sustainable Development, a subgroup of Materials Research Society, emerged out of the talent and enthusiasm of the Student Congress. A healthy dialogue of voices from around the world and among energy and sustainability experts, decision makers, students, and early-career researchers characterized that meeting. This LinkedIn forum (1) aims to extend that dialogue to a broader community, track progress, and forge new ground; (2) addresses materials research challenges to meet global energy and environmental needs for sustainable development and (3) examines the juncture of emerging science, cost-effective scale-up, and public interest, with a focus on arriving at meaningful solutions.

2011 World Materials Summit

DECLARATION

VISION: It is an inherent right of everyone on Earth to have access to clean energy and 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.

The 2011 World Materials Summit in Washington D.C., USA, identified opportunities and mechanisms to facilitate international cooperation focused on addressing materials solutions related 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. Recycling and 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 materials science and engineering directly to the purification and processing 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 as a personal responsibility.

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, potential reductions), lifecycle analysis, risk assessment and reduction, 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 policy makers 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.

Expert and Student Congress panel reports available at **www.mrs.org/2011wms**.

MRS MATERIALS RESEARCH SOCIETY *Advancing materials. Improving the quality of life.* E-MRS MRS

World Materials Summit Publications List

Web, www.mrs.org/2011wms

- Declaration
- Tutorial presentations
- Keynote and plenary presentations
- Expert panel presentations
- Expert panel reports
- Student Congress panel presentations
- Student Congress panel reports

***MRS Bulletin*:**

- Editorial by Student Congress participants published in Dec. 2011 *MRS Bulletin*, Energy Quarterly section
- Report to be published in Feb. or March 2012 *MRS Bulletin*

World Energy and Sustainable Development Brochure (to be published April 2012):
Summarizes and expands on the content and outcomes from the World Materials Summit presented at a level useful to a more general audience and appropriate for a worldwide audience.

Student Congress Brochure (to be published April 2012):
Summarizes and expands on the content and outcome from the World Materials Summit Student Congress and their plan for action.

Social media

- Student-run linkedIn group: World Materials Summit Student Congress 2011. It has 26 members, mostly participants from the Student Congress.
- MRS formed LinkedIn subgroup, Materials for Energy and Sustainable Development.
    - As of Jan. 4, over 200 members have joined representing 34 countries (includes many of the Student Congress participants as well as high-level professionals)

Materials360 electronic newsletter

- Immediately after the meeting ran highlights from some of the keynote and plenary presentations.
- Publicized LinkedIn group regularly

Podcasts (in development):

- Dave Ginley/David Cahen on the MRS textbook: *Fundamentals of Materials for Energy and Environmental Sustainability*
- Sergio Alcocer (Undersecretary, Ministry of Energy, Mexico
- Student Congress interviews

Energy Quarterly

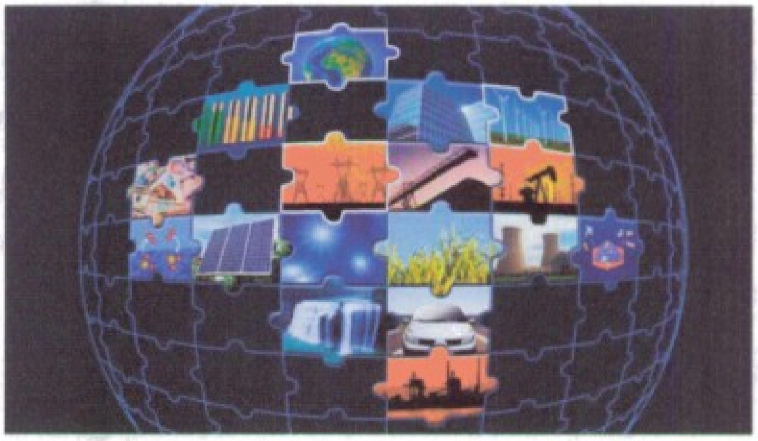
News and analysis on materials solutions to energy challenges
www.materialsforenergy.org

Inside:

Images incorporated to create the energy puzzle concept used under license from Shutterstock.com.

To suggest ideas for ENERGY QUARTERLY, to get involved, or for information on sponsorship, send email to materialsforenergy@mrs.org.

MRS Bulletin



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

www.mrs.org/2011wms

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.

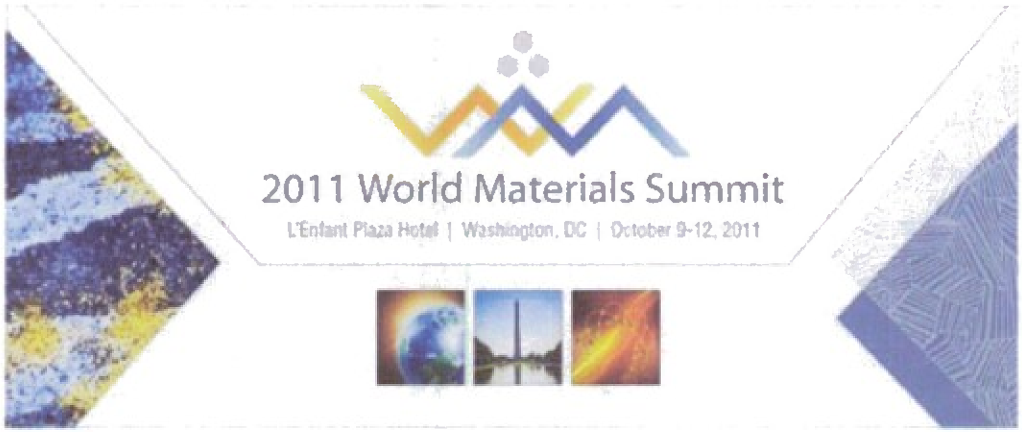
The magnitude of the task necessitates coordination among nations, and nations do not always agree. Raw materials, monetary resources, and technological capability are not distributed evenly. Thus some participants argued strongly for renewables such as wind and solar, while others pointed to the scalability 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 MATERIALS RESEARCH SOCIETY
Advancing materials. Improving the quality of life.

Keynote & Plenary Presentations



The following are keynote and plenary presentations given by energy and policy experts at the 2011 World Materials Summit. Additional presentations will be posted as they are available.

Monday, October 10, 2011

- **Introduction**
  Meeting Chairs: Gabriel Crean, David Ginley, Yafang Han, Alan Hurd

KEYNOTE SPEAKERS

- **Report on the First Quadrennial Technology Review**
  Steven Koonin - Undersecretary for Science
  US Department of Energy

- **Key Enabling Technologies: A European Perspective**
  Gabriel Crean - Scientific Director
  Commissariat à l'énergie atomique et aux énergies alternatives (CEA)

- **CO_2 as a Cheap and Renewable Fuel for the Polymer Industry**
  Xianhong Wang
  Changchun Institute of Applied Chemistry, Chinese Academy of Sciences
  [Presented by Dujin Wang]

- **Mexieo – Trends in the Energy Sector: A Proposal on Nanoteehnology for Solar Energy**
  Sergio Alcocer - Undersecretary for Energy Planning and Technology Development, Mexico

PLENARY SPEAKERS

- **Global Energy Challenges and Sustainability**
  Harry Kroto - Florida State University

- **Global Energy Flows**
  Lynn Orr - Stanford University

- **Materials Challenges in Renewable Energy: The Renewahle Energy Transition**
  George Crabtree - Argonne National Laboratory and University of Illinois at Chicago

- **The Challenge of Water**
  David Cahill - University of Illinois at Urbana-Champaign

- **Bringing Photovoltaie Energy Conversion to the Terawatt Level**
  Patrick Bressler - Fraunhofer-Gesellschaft

- **Life Cyele Assessment as a Component of Materials Seienee & Engineering for a Sustainable World**
  Duan Weng and Hongtao Wang
  Tsinghua University
  [Presented by Duan Weng]

- **Eleetrieity Grid**
  Paul Waide
  Navigant Consulting

- **Future Vehieles and Energy**
  Jerry Gibbs
  US Department of Energy

- **Resouree Availability: Charaeterizing Risks & Identifying Researeh Opportunities**

Randolph Kirchain
Massachusetts Institute of Technology

- **Nuclear Power: Perceptions, Performance, Promises**
  V. S. Arunachalam
  Center for Study of Science, Technology and Policy (CSTEP)
- **Advances in Materials Sciences**
  William F. Brinkman
  US Department of Energy
- Poster Session & Reception

Materials Research Society: 506 Keystone Drive, Warrendale, PA, 15086-7537, USA
Phone: 724 779.3003 Fax: 724 779.8313 Contact Us: info@mrs.org

2011 World Materials Summit

Panel Discussion Report

Panel on Buildings and Lighting

Current state of the technology (Bird's eye view)

- there is a gap between the needs of the building sector (for energy demand and savings/efficiency with equal amenity) and the current focus of materials scientists.
- In China and emerging markets, the state of the technology is sufficient for major changes in energy efficiency…Enormous potential for the built environment to achieve dramatic energy use reductions

Long-term vision or goal (toward 2030)

- *Relationships will be strengthened among materials scientists, building scientists, building designers (architects), the building materials industry, and policy makers, all working together so as 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.]

Major research and technological needs and opportunities in support of vision

- Understand location-specific dynamics and location-dependent material demands,
- Develop better whole building systems-scale simulation and optimization tools with easy user interfaces – provide tools to the building designer
- Expand research in phase change materials,
- Develop cost-effective semiconductor materials and devices for sensors, lighting, communications, power electronics
- Develop cost-effective other materials for integrative sensors, microelectronics, lighting, energy harvesting, communications and controls

Major research and technological needs and opportunities in support of vision (cont.)

- Expand thin film research into meso-scale thickness range (200 nm - 5 micron) and variable porosity (from compact to 50%) films for heat exchange fins, ionic exchange membranes, photovoltaic thin films, electrochromic films, etc.
- Increase efficiency of HVAC systems with novel heat exchange technologies, working fluids, innovative dehumidification technologies, making use of low-grade thermal energy (e.g. Devap)
- Develop materials with controllable and variable surface optical properties (with spectral control) to optimize the interface between the building the environment
- Develop adaptive vapor retarders (sometimes an impermeable humidity barrier, sometimes allowing moisture vapor permeability)

Connection of research developments to achieving vision/goals

- **Basic materials researchers should understand the state of the art within industry:** real bottlenecks, challenges to deployment or bridging the valley of death, recognizing IP issues that serve as barriers to collaboration and learning both regionally, nationally, and internationally.

- **Basic materials researchers should develop much greater understanding and appreciation for Life Cycle Assessment.** We recommend developing strengths/skills in Life Cycle Inventory for materials (database generation) and Life Cycle Assessment—both of which are critical to the building industry.

Connection of research developments to achieving vision/goals (cont.)

- **Recommendation to increase the dialogue between building designers, building scientists, policy makers, and materials producers/manufacturers around regulations.** [e.g. example of porous cement from the The Inst. of Technical Supervision and Research for the Building Materials Industry]
- [e.g. also changing building codes to minimum cost points]

Opportunities for international cooperation to accelerate developments in this field

- **International Cooperation:** Western researchers do not typically have a strong familiarity with the Chinese built environment and social considerations, especially in rural areas. In order to accelerate mutual understanding, we recommend establishing professional society offices in China to encourage exchange of information. Also consider matching funds with China to increase research scientist visiting fellowships to China.
- **Major opportunity:** in developing insulation in China, for low-cost flame-retardant, high performance and long-lasting properties. There is great potential for deployment, with key emphases on applications, processing and reproducibility. Likely this applies to other building technologies as well.

Impediments/hindrances/stumbling blocks to international cooperation

- A crucial stumbling block in the building industry is in assuming that all buildings exist in that singular country—while building scientists emphasize that climate and cultural norms are important in making materials decisions for highest utility.
- Lack of recognition for IP issues is a barriers to collaboration and learning both regionally, nationally, and internationally.

Policy, support, outreach, and promotion opportunities

- **Recommend connecting to grid and storage panel priorities.** Building energy control systems must be integrated with the grid for demand response mechanisms. There is long-term work developing for agent based system in a building to negotiate for power vs costs/value, and this extension is being explored for the grid as well.

- **Open questions:** 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.

Concluding/summary slide

Top points from this committee:

- 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/optoelectronic materials, but must be constrained by extremely low costs and high performance.

Panel Members

- Jerry Simmons, Sandia National Labs: lead
- Jeffrey Brownson, Penn State: scribe
- Eric Amis, United Technologies: co-lead
- Dujin Wang, Institute of Chemistry, CAS
- Claes Göran Granqvist, Uppsala University
- Ron Judkoff, National Renewable Energy Lab
- Luoyi Xu, Institute of Technical Information for Building Materials, China

2011 World Materials Summit

Energy Fuels Panel

Chair Russ Chianelli UTEP

Co-chair David Cahen Weizman Institute

James Brainard NRL

Jose Olivares Los Alamos

Xu Zhang Beijing University

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

E-MRS

C-MRS

Major Technological and Research Opportunities

- Materials Science & Research **Basic** - Challenges
- Materials Science & Research **Applied** - Challenges
- Approaches to achieve future technologies – **Next Generation**
- **Green** Processes and **Green** Materials Approaches

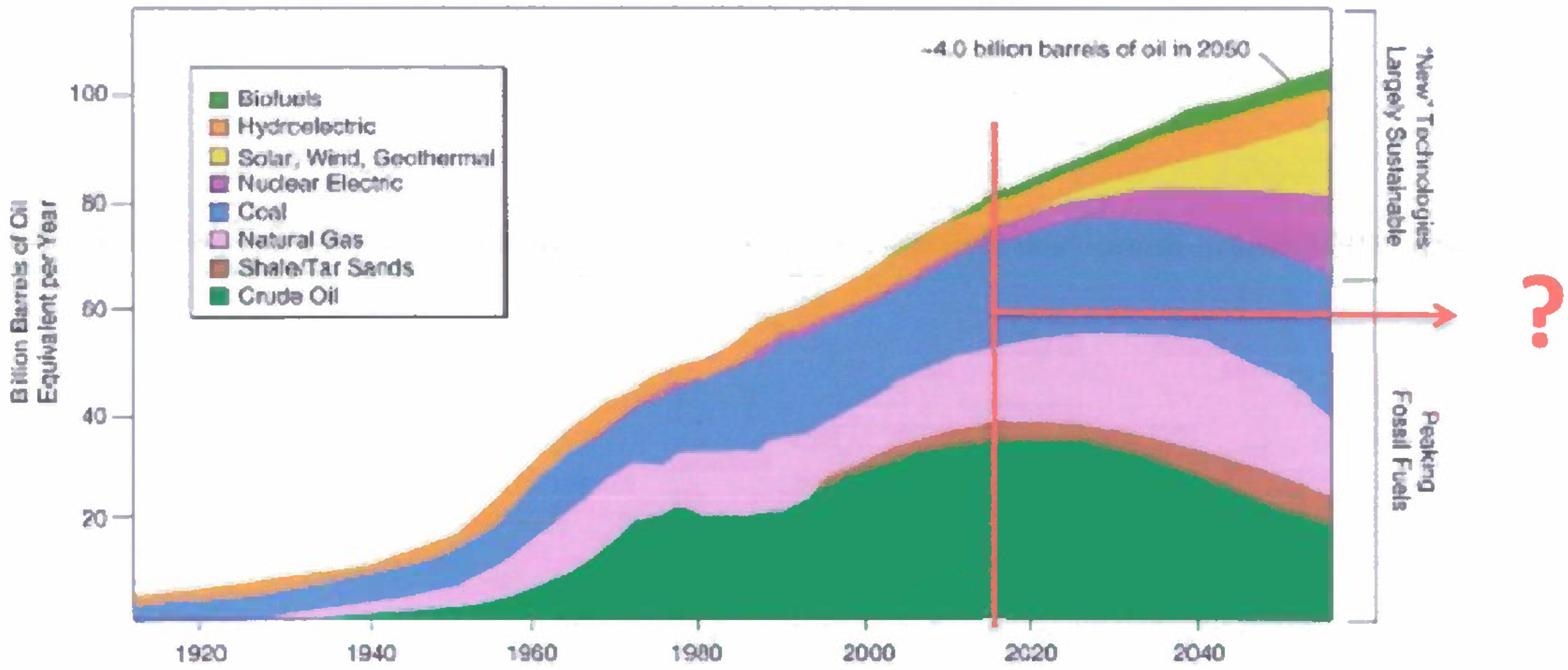
2011 World Materials Summit

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

E-MRS

C-MRS

World Energy Demand—Long-Term Energy Sources



Sources: Lynn Orr, *Changing the World's Energy Systems*, Stanford University Global Climate & Energy Project (after John Edwards, American Association of Petroleum Geologists); SRI Consulting.

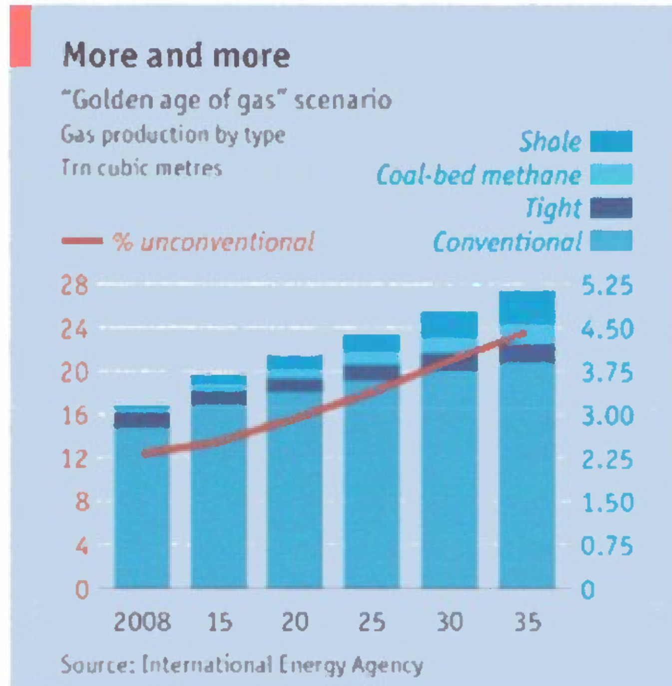
End of Oil 2006

2011 World Materials Summit

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

E-MRS

MRS



2011 World Materials Summit

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

Areas of Study for Energy Fuels

Bio-Materials

Bio-Processing

Optimization of Bio-Fuels Production

Enzyme Catalysis

Catalysis

Photo-Catalysis

Carbon Capture

Materials for Safe Fossil Fuel Production

Bio-Materials – Feedstocks for Bio-Fuels

Bio-Materials Structure

Lipids and Lignocelluloses

Bio-Materials Deconstruction

Bio-Processing

Metabolic Engineering

Bio-mimetic Systems and Materials

Synthetic Biology

Optimization of Bio-Fuels Production

Land, Soil, Water and Resource Use

Cultivation and Processing Materials

Enzyme Catalysis

- Cellulases/Lipase
- Enzyme Engineering

Catalysis

- Fundamental Understanding for Prediction of Catalytic Properties
- More Efficient Use of Fossil Fuels
- Greener Processing

Electro-Catalysis

- Synthetic Fuels

Photo-Catalysis

- Artificial Photo-Synthesis

2011 World Materials Summit

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

E-MRS

C-MRS

CO_2 Conversion

Catalysis

Better Fischer Tropsch and Water Gas Shift Processes

Methane Reforming with CO_2

Electro-Catalysis

Synthetic Fuels

Photo-Catalysis

Artificial Photo-Synthesis

Materials for CO_2 Capture

Materials for Safe Fossil Fuel Production

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

2011 World Materials Summit

Obstacles and Opportunities

- Interdisciplinary Approach Required: Basic/Experimental/Application/Commercialization and Communication.
- New Funding Models Required for Interdisciplinary and Translational Approach to Research and Education. For example EU R&D through Innovation and NIH Translational Programs.
- Student Interdisciplinary/Transitional Teams need new funding mechanism.
- Reduce “Hype”: Effective science, technological, economic and energy balance evaluation.
- World implementation of Sustainable Energy for research and development. For example, “Scientists and Engineers without Borders”, Kenya and Nigeria and intergovernmental agency funding.
- International, *IP neutral*, Catalyst Testing Laboratories.

Energy Fuels for the Future

- Prepare *Now* through Research and Development for Transition to Bio-Fuels

- Discover Improved Catalysts for Energy Fuels

- Create Enhanced International Environment for Translational Energy Fuels Science

2011 World Materials Summit

Nuclear Energy Panel

Todd Allen (Chair), V. Arunachalam, Mark Bourke

MRS MATERIALS RESEARCH SOCIETY E-MRS C-MRS

Nuclear Energy

Public Perception Drawback-***Fukushima has altered public acceptance and perception of risk associated with nuclear power***

Critical question that affects nuclear deployment: ***Are nations collectively (or individually) ready to adopt measures to control greenhouse gasses?***

- Benefits
  - High power per unit mass of fuel (less mining, less waste)
  - Fuel is cheap, therefore low operations costs
  - No carbon emission during operation (better for climate change)
  - Significant fuel resource, especially if recycled
- Drawbacks
  - Radioactive waste requires long-term monitoring & control
  - Large plants are costly and take time to build (requires confidence in long-term profits thus desire to maximize plant component life)
  - Safety Concerns-Decay heat must be controlled to protect from fuel failure (e.g., Fukushima station blackout)
  - Unique regulatory regime in each country
  - Single large accident anywhere affects future prospects everywhere

Overview Thoughts from Panel

- Although the approach of individual countries will differ, nuclear power usage is a likely continued source of energy
  - Examples:
    - Germany versus France & Czech Republic, Japan, China & India
    - Light water reactors, Generation IV reactors
  - 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 public policy makers 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 material science solutions, will improve the ability to convince the public to be increasingly accepting 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 critical 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.

Likelihood of Nuclear Energy

Key policy questions

- Do we need to advocate for modern technology, even knowing it comes with an increased cost (e.g., would you let your mom drive down I-95 in a model-T or buy her a modern car with air bags and a hands free phone, given the model-T is paid for)
- Can public policy makers be informed enough to avoid "shifting the scale" during the accident as this shifting leads to the belief that we don't understand the technology (true for nuclear as well for oil spills and blown up oil fields)
- Can we set international standards of collaboration (visa policy, technical exchange rules under export control, funding opportunities that cross country barriers) to optimize use of resources and to facilitate a common language regarding the technology (e.g., why is the U.S. setting a larger evacuation zone for its citizens in Japan than the Japanese government is setting for its own citizens)
- Can international cooperation be a focus of the study on safer, proliferation-resistant, economic, and waste-minimized reactor systems as embodied in the Generation IV program definition or the fusion programs? How does a commercial company like TerraPower build a Generation IV system working globally?

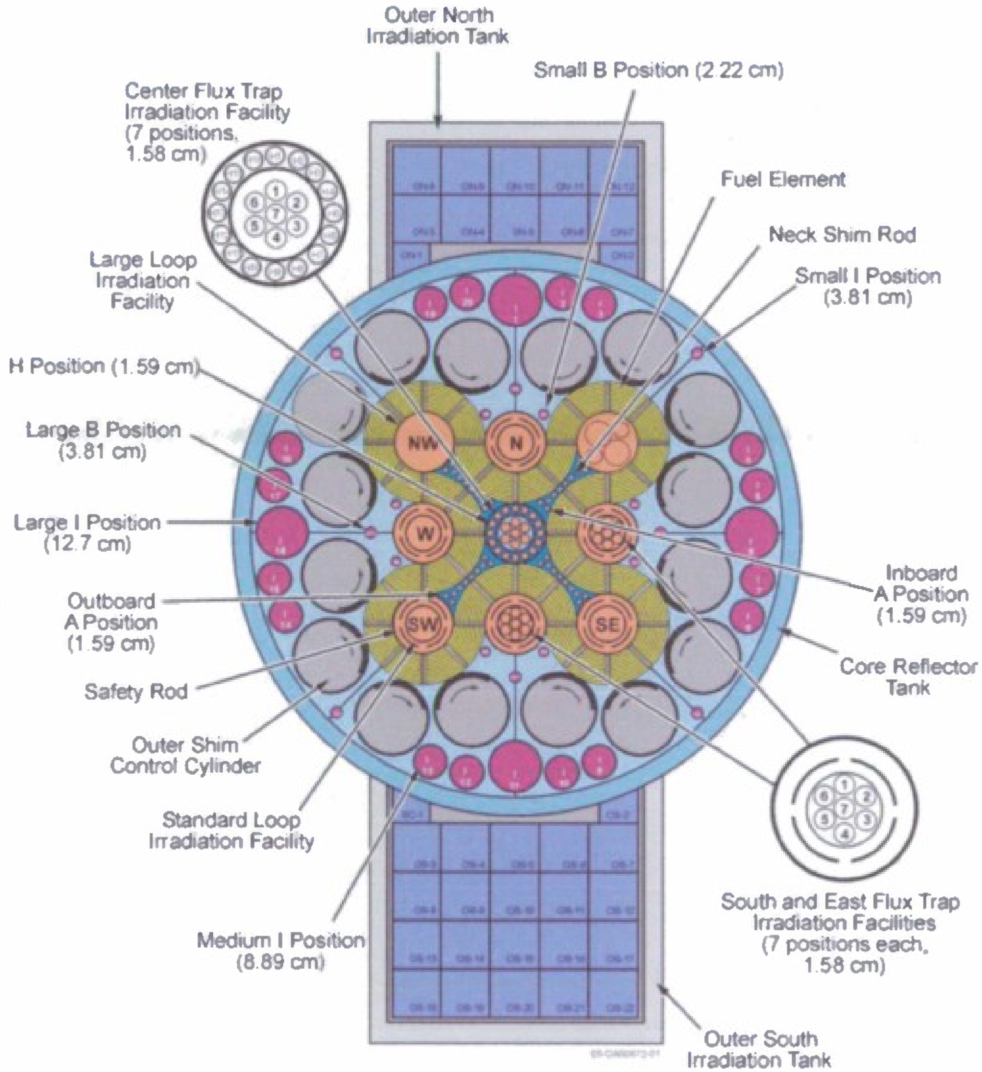
Material Science Challenges

- Public policy makers typically balance the opinion of technologists who advocate a technical solution (you) and the general public (my mom) who benefit and are affected by the technology choice.
- Informing public policy makers of the ability of material 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. Examples:
  - Developing a waste form that contains radioisotopes to an acceptable level
  - Providing material science solutions that meet safety requirements for extended lifetimes, including LWR and Generation IV systems. Generation IV systems such as sodium systems have been shown to be inherently safe against loss of cooling but are still too expensive to compete with LWRs, advanced materials may reduce costs
  - Developing cladding materials (e.g., other than zirconium-base materials) that mitigate hydrogen explosions while minimizing changes to reactor operations
  - Continuing non-proliferation research as an international imperative (assay, detection, proliferation resistant fuel cycles) to the safer deployment of nuclear systems
- Access to a fast(er) neutron source is critical for both future advanced fission and fusion system development

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

ATR NSUF

- Mechanical properties
  - Nanoindenter/AFM
  - Small sample mechanical testing
  - Automated micro-hardness tester
- Analysis at micro- and nano-scale
  - FEG-STEM-chemical and structural analysis at the nano-scale
  - Atom Probe-identify single atoms (few in world available for use on radioactive material, none on fuel)
  - Raman spectroscopy-light scattering to understand atomic structure
  - SEM hot stage-real time analysis of changes in structure due to temperature
- Sample Preparation
  - Dual-beam FIB #2
- Fuel Examination
  - Consolidated Fuel Exam Machine feasibility study-would save space in HFEF



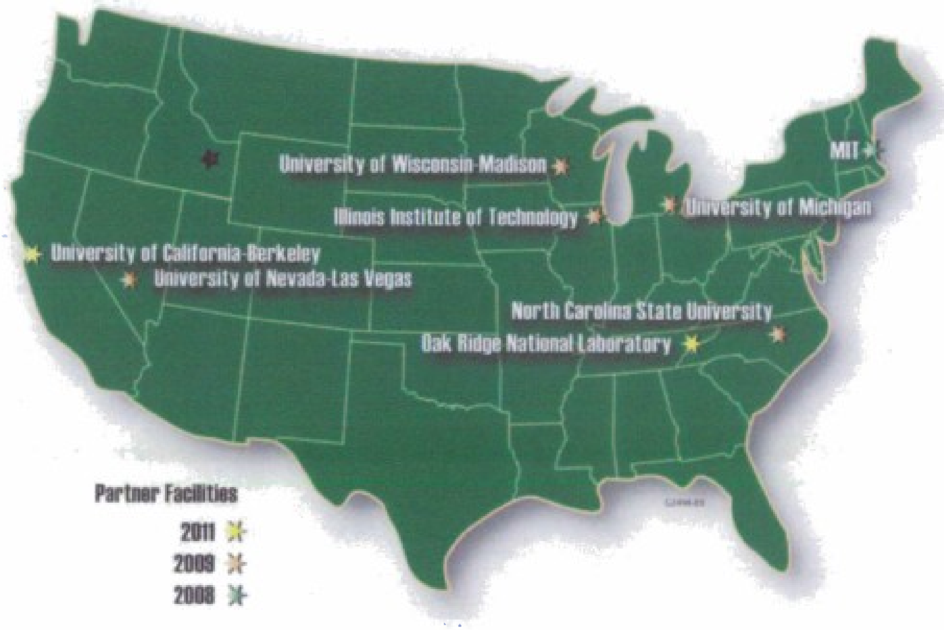
MRS MATERIALS RESEARCH SOCIETY
Advancing materials. Improving the quality of life.

E-MRS

MRS

Collaboration

- University Partner Facilities
  - MIT (MIT Reactor)
  - Illinois Institute of Technology (Advanced Photon Source)
  - University of Wisconsin (Characterization Lab for Irradiated Materials)
  - University of Michigan (Irradiated Materials Testing Lab)
  - NCSU (Pulstar Reactor)
  - UNLV (Electron Microscopy Laboratory)
  - UC-Berkeley
  - **Collaboration with Oxford University**



National User Facilities:

- **Advanced Photon Source**
- **SHaRE**
- **LANSCE, NIST**

Expansion to include major facilities in France, Japan, China, India, and other countries with significant nuclear research infrastructure would be optimal

2011 World Materials Summit

User Facility Concept

- Traditionally, major facilities have resisted accepting the burden of working with radioactive materials. Changing that mindset allows the application of modern material science to nuclear energy materials issues (e.g., modeling and experiment at the same time and length scales)
- The costs of working with radioactive materials is costly so the user facility model allows for anyone with the best idea is allowed access to necessary capability
- Once the U.S. establishes the ability to analyze radioactive materials routinely in user facilities, the next logical step would be to take that international (e.g., routine access to fast reactor irradiation space in India for U.S. scientists and routine access to BES user facilities in the U.S. for Indian scientists)
- Scientists can prove the use of user facilities across funding agencies, proving to policy makers the value, without the need for formal arrangements (DOE NE and DOE BES facilities)
- Mechanisms for international partnerships need improvement
  - Coordinated funding or equipment sharing mechanisms involving international agreements
  - Student exchanges & travel support
  - Removing barriers to export control, & improvements in visa approval time
  - ***Is the ITER (or CERN) model relevant to designing Generation IV systems***

Key Elements: Nuclear

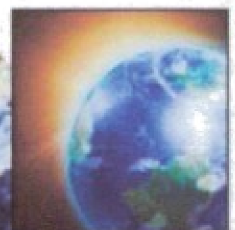
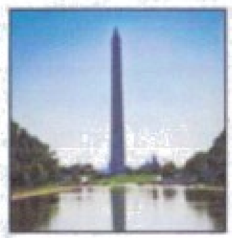
- To take advantage of the carbon free generation possible through the use of nuclear energy, nuclear systems must continually strive for improved safety, acceptable economics, reduced proliferation, and minimization of the waste stream. Improvements in materials technology, and the subsequent informing of the public and public policy makers of the improvements, is critical to meeting this improvement 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. 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 critical. 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.

2011 World Materials Summit

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

10/11/2011

Policy and Education Panel


Assumptions

- Other Groups Will Recommend Specific Policies For Their Technology Category
  - Our Group Did Not Address
- Materials Scientists Need To Be Better Spokespersons For The Public
- Policies of Governments Are A Result Of Informed Citizens and General Public
- There Is A Natural Tension and Need For Balance Between Competition and Cooperation
- Examples Of Recommendations Should Be Specific Enough For Action

Outline

- Educating Materials Scientists To Be Better Spokespersons With The Public
- Aligning International Cooperation

Educating Materials Scientists To Be Better Spokespersons With The Public

- #1 - System Level Thinking
  - Post Doc level
  - Graduate students
  - Entry level freshmen
  - Increased understanding over time
  - Recognize differences for each country
  - Federal grant expectations for public outreach
  - Education kits
    - Survey and share information across countries
  - Build a Community That Is Better Informed
    - Develop workshops at major meetings
    - Including other groups – e.g. social, economic, and environmental – interacting with materials science students

Educating Materials Scientists To Be Better Spokespersons With The Public

- #2 – Outline Challenges Beyond Scientific Research
  - Currently we engage mainly in science education
  - Large list of other factors influencing energy
  - Show linkage of research to innovation
  - Professional societies should make paradigm shift to include research to innovation in our meetings
  - Recognize need for different vocabulary/thinking – e.g. communities that have a stake in sustainable issues
  - Mapping world needs in energy with materials science
  - Interactions increased by societies, universities, and funding agencies

Educating Materials Scientists To Be Better Spokespersons With The Public

- #3 – Highlight Materials Impact on Our Daily Lives
  - Educate and present examples
  - Balance applications with need for and the importance of research programs
  - Look for experiences from each country that can be shared
  - Involve industry, government agencies, and universities
  - Analyze economic impact on GDP of materials research and innovation
  - Create interaction with others for better understanding
  - EMRS/CMRS/MRS inventory within materials and related scientific societies – e.g. APS, ACS, SPIE, IEEE, etc.

Aligning International Cooperation

- #1 – Recent Efforts Specific to Energy in Europe and US Are Very Timely And Should Be Maximized ASAP
  - Horizon 2020 and QTR
    - Identify Joint S&T Opportunities – e.g. battery standards – identify and establish collaborative efforts
    - Look beyond science only opportunities for joint work – e.g. social economic factors as an example, energy efficiency
    - Who should be assigned this important task? timely response
    - Select common energy goals
    - Search for other countries and regions beyond EU and US that have plans in common
    - Look for opportunities to include developing countries in these areas of high priority

Aligning International Cooperation

- Continued
- Manufacturing Science
  - Attention currently underway in all countries where the front end science can make a big impact on industry
  - Look for alignment opportunities
  - Focus on manufacturing science specific examples in energy
  - Note: industry already does this in many sectors

Aligning International Cooperation

- #2 – Recycling
  - Cradle to grave design and mindset
  - Identify and anticipate wide spread implementation of energy technologies and develop a mentality for recycling – e.g. PV, batteries, critical materials, etc.
  - Standards
  - Legislation
  - Practical consumer education
  - Eliminate negative impact on developing nations
  - Think about long-term impact and economics

Renewable Energy Panel

The discussion focused on the following four areas and solar energy was used as the exemplar

1) Materials Challenges

2) R&D

3) Manufacturing

4) Deployment

Three actionable topics emerged from the discussion

1) Materials Availability

2) Sustainability

3) Codes and Standards

Recommendation 1: MRS should develop international and public-private partnerships to generate the Google Prospector. 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.

Recommendation 2 – the MRS needs to champion educational outreach programs touting the necessity of end-of-life materials recovery practices. MRS should make life cycle materials engineering a focus area within its current portfolio of symposia and workshops.

Recommendation 3: Establish continental testing and validation centers (ie., NREL-Sandia, AIST, Fraunhofer-ISE, Africa, China, Australia, India, Mexico) to ensure a level playing field and consumer confidence. Implement a series of international workshops to establish the framework of this new international network. Need to establish network of funding sources (i.e., governmental and private trade associations) to support these centers and activities).

Recommendation 4 – In symposia and workshops directed toward planning for renewable – grid interconnectivity, we need to reserve discussion for the special opportunities of developing areas and not focus exclusively on established grids.

Recommendation 5 - MRS 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. A funding level of $25 M per year for 5 years to support each team is appropriate.

Overall Objective of Panel

- Describe the current state of the technology
- Identify a long-term vision or goal (e.g. to achieve by 2030)
- Prioritize major research and technological needs and opportunities in support of that vision
- Suggest how research developments will lead to progress toward that vision
- Suggest where international cooperation is needed to accelerate developments
- Identify impediments, hindrances, and stumbling blocks to international cooperation
- Identify policy, support, outreach, and promotion opportunities
- Determine recommendations/open questions

Research and Development

1) Organic PV Development

Organic photovoltaics are among the most promising and most challenging solar cell technologies. Their rapid progress in raising efficiency to near 10% (is this right?) 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. An international research community with a footprint in many countries is already established.

A host of foundational questions abounds. Can non-crystalline organic films achieve "device quality" properties? Can they be incorporated into conventional device designs? Are there alternative device designs that can be utilized? What will the sustainable manufacturing challenges be? What will the end-of-the-life issues be? Though fundamental to eventual scale-up and deployment, these issues remain largely unexplored and are ripe for coordinated pre-competitive research attention.

Recommendation: MRS 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. A funding level of $25 M per year for 5 years to support each team is appropriate.

Research and Development

2) 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. The restriction of innovative alternative energy technologies to earth abundant materials capable of scale up to TW proportions is one of the most important strategic R&D conditions for effective renewable energy development.

Recommendation: MRS should develop international and public-private partnerships to generate the Google Prospector. 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.

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.

Recommendation – the MRS needs to champion educational outreach programs touting the necessity of end-of-life materials recovery practices. MRS should make this a focus area within its current portfolio of symposia and workshops.

Manufacturing and Deployment

1) Codes and Standards

Global network of institutions to identify and established necessary codes and standards, including those needed to verify performance and reliability.

Recommendation: Establish continental testing and validation centers (ie., NREL-Sandia, AIST, Fraunhofer-ISE, Africa, China, Australia, India, Mexico).

Implement a series of international workshops to establish the framework of this new international network.

Need to establish network of funding sources (i.e., governmental and private trade associations) to support these centers and activities).

This is best formulated by the solar experts on the panel-gwc

Manufacturing and Deployment

The broad potential for international cooperation in renewable energy must be tempered by the recognition of different national or regional needs depending on the stage of energy development. For example, the needs of the developed and developing world for electricity may be strikingly divergent. The developing world often cannot afford the resources or time required to establish and extend a grid to serve every village. Instead, distributed power based on a microgid or independent solar cells with a high reliance on local storage brings the greatest benefit to the greatest number in the shortest time. In the longer term, new grids need to be planned that will form a coherent whole instead of the disorganized patchwork typical of the developed world. Lacking a grid legacy, the developing world can plan a much more rational and economic route to a modern and effective grid superior to those in the developed world. Costing models for the disparate applications in the developed and developing world need to be explored.

Recommendation – In symposia and workshops directed toward planning for renewable – grid interconnectivity, we need to reserve discussion for the special opportunities of developing areas and not focus exclusively on established grids.

2011 World Materials Summit

Panel Discussion Report

Resource Assessment

Scope

- The panel determined 4 topics to be within the resource assessment scope
- Primary resources
  - Mines
  - Recycled materials
- Substitution as an alternative when there are shortages
- Analysis methods for resource production including materials, water, energy, land, greenhouse gases…

Current state of the technology (Bird's eye view)

- Mining: prospecting and extraction done by traditional methods, has become more efficient in recent years
- Recycling: break into small pieces and dissolve to recover metals, only certain metals can be recovered
- Substitution: done *ad hoc* in response to supply shortage
- Analysis: methodology to compare resource use for different technology solutions

Long-term vision or goal (toward 2030)

Having the raw materials needed for energy technologies when they are needed, provided sustainably, at an affordable price

Major research and technological needs and opportunities in support of vision

- Mining: challenges are sustainable, efficient mining methods, lack of understanding about ores containing rare elements, appropriate regulations
- Recycling and substitutions: lack of systematic knowledge about appropriate methods
- Analysis: lack of information on materials, resource needs and processes

The supply chain imply new « connected » research and information systems

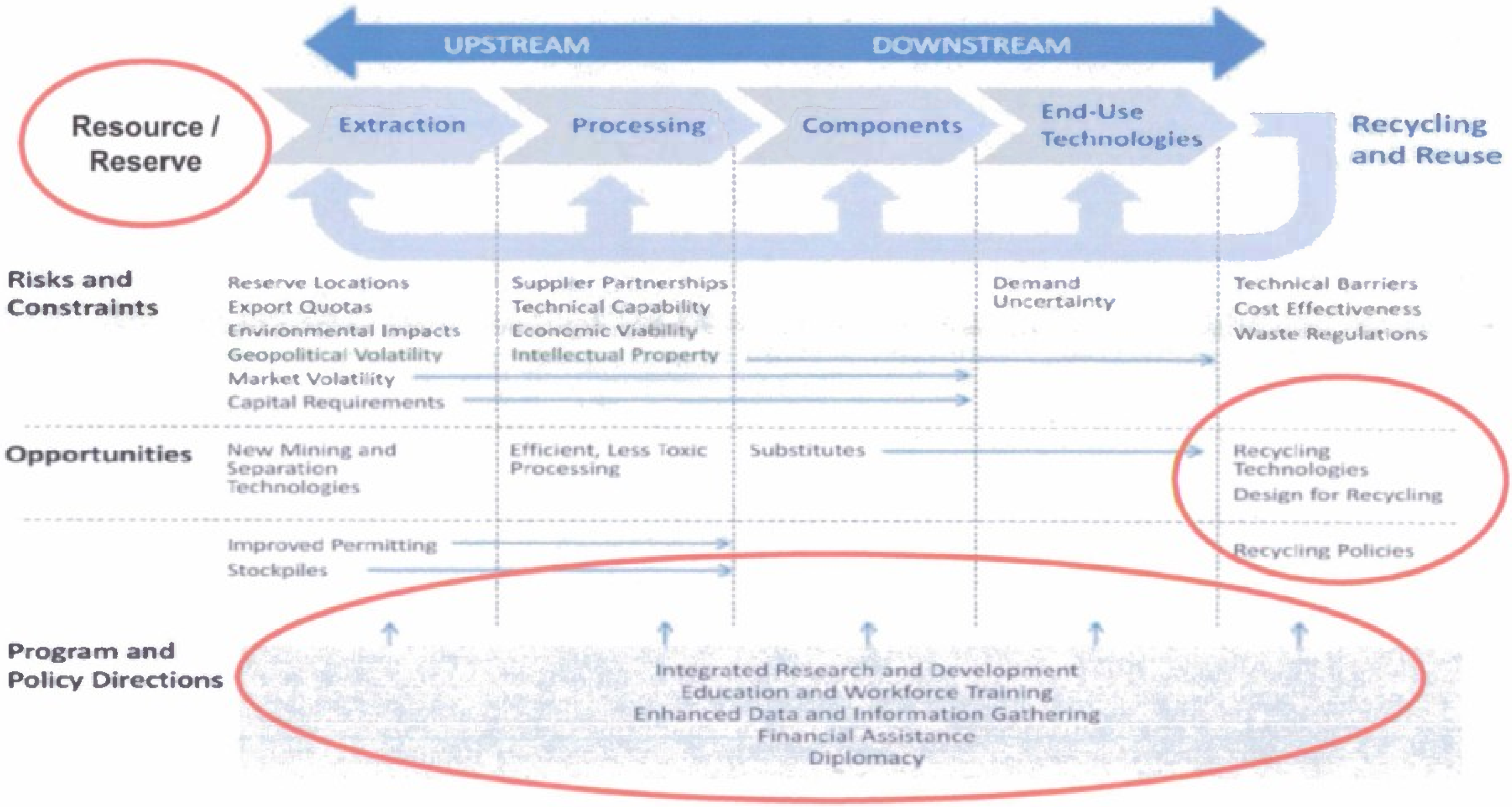


Figure ES-3. Program and policy directions and the critical material supply chain

References

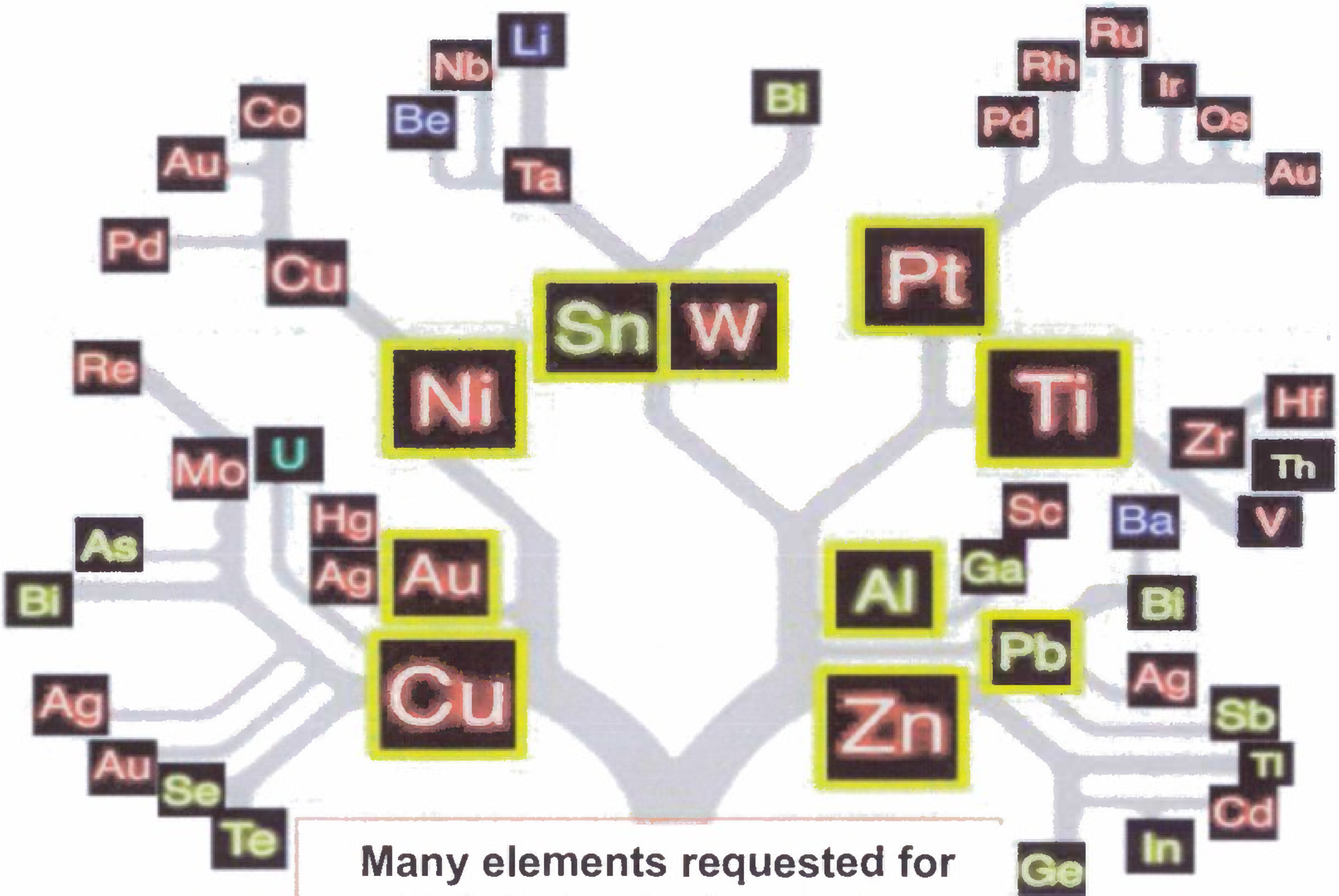
NAS (National Academy of the Sciences). 2008. Minerals, Critical Minerals and the U.S. Economy.

Research and Innovation opportunities

- Reduce risk by **knowledge of natural resources and information on materials needs of new technologies** – communication between suppliers, economists and technologists
- **Information on resources and reserves**, and on actual consumption for new energy technologies – reliable and timely to enable accurate projections of needs
- Geosciences – to better **identify good sources especially of scarce materials**. "surgical" mining rather than extracting a lot of rock for a little final product
- To establish a **systems methodology that will consider a process or product from the mine through to recycling to evaluate impacts**
- Better, more efficient and benign **extraction and refinement chemistry**
- **Recycling and separation processes** (chemical, biological, physical)
- Research on **properties of and processes using recycled metals**
- Learn efficient chemistries using **CO2 as a raw material**
- **More efficient capture of CO2** from process waste gases
- Research **linking discovery of material to prototype to scaleup to reliability**
- **Science for substitutions through materials discovery** (alloys, nanomaterials, components): composition, structure and morphology

MRS MATERIALS RESEARCH SOCIETY
Advancing materials. Improving the quality of life.
E-MRS
MRS

Where are the new raw materials



Many elements requested for high technologies are by-products of common metals

MRS MATERIALS RESEARCH SOCIETY Advancing materials. Improving the quality of life. E-MRS

Economic comparison of the main routes of energy storage from CO_2

- Sun…and…….bioalgea……… 150 to 300$/barrel
- **Coal- biomass-byproducts** 70$/barrel
- Renewable energy and electrolysis 80$/barrel
- **Decarbonated energy electrolysis** 55$/barrel
- **Coal +CCS+HydrogenCH4 (US)** 40- 50$/barrel

These data are the breakeven price for oil production

(oil cost Sept 2011 WTI (85$/b)

- **These data depend of many parameters such as:**

capex and opex of the installations,
interest rate,commodities,insurance,risks,(coal,gas,oil) cost,electrical cost

- Market place: ETS of CO_2 and regulation decisions (EEC,EPA..)

CO_2: a recycled source for new fuels and other materials

What is being done today?

- New awareness of limits over past few years and **rebuilding of mining and extraction research**
- New programs in **recycling chemistry and biological recycling processes**
- New efforts to develop **cost models for full mine to product systems**, eg life cycle assessment, resource and environmental aspects
- **Basic research needs being codified** to identify grand challenges for energy including materials substitutions and discovery

Opportunities for international cooperation

- **Coordination** of research needs and programs (multilateral)
- Identify priority areas through **focused multi-society international workshops** (industry, government, chemistry, materials, physics, engineering, mining, geosciences, economics) (see D. Arent in backup section)
- Create **networks of information**, develop information systems
- Develop and validate **analysis methods** for resources, economics ("mineral intelligence", end uses, costs etc)
- **Training of workforce** in countries with active mining (eg China) to accelerate rebuilding of workforce in the west
- **International agreements on exchange of funds and IP** in joint work - process not easy today. (See D. Arent in backup section)
- **Tools for materials discovery** (synthesis and characterization, modeling and computation, testing)
- **Funding of major research facilities** (microscopy, spectroscopy etc) specialized for minerals research and shared internationally

	analysis	To scientists R&D	To policy makers
resource	LCA, Systems methods for predictions, national/global resources inventories	Geosciences, Measurements to support LCA, separations science	Address national needs, need consistent support in the face of cyclic shortages, international cooperation, information collection
recycle	Resource use and needs	Design for recycle, separations science, new feedstocks such as CO2	Regulations, incentives, standards
substitute	Resource use and needs, sustainability analysis	Materials discovery	Support long term pre-competitive research

LCA – life cycle assessment

All materials used for a product (raw resource plus resources used to make the product)
Materials scientists should be aware of cost when working on performance

Panel Participants

- Jacques Amouroux (co-chair)
- Douglas Arent
- Pol Guennoc
- Frances Houle (chair)
- William Tumas
- Hongtao Wang

BACKUP COMMENTARY AVAILABLE ON REQUEST

2011 World Materials Summit

Panel Discussion Report

Smart Grid/Storage Panel XXXX

2011 World Materials Summit

MRS MATERIALS RESEARCH SOCIETY
Advancing materials. Improving the quality of life.
E-MRS
MRS

Overall Objective of Panel

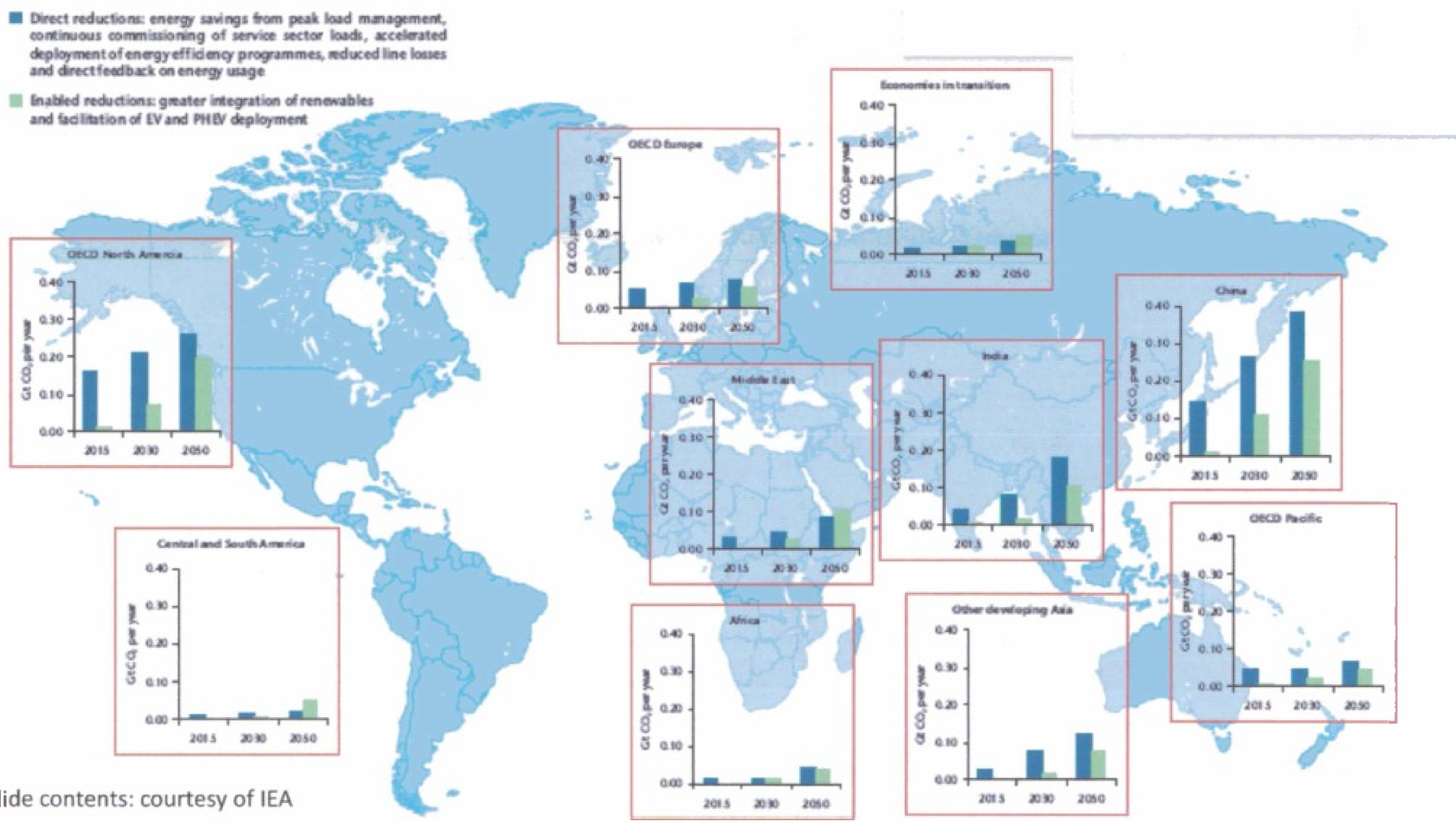
- Describe the current state of the technology
- Identify a long-term vision or goal (e.g. to achieve by 2030)
- Prioritize major research and technological needs and opportunities in support of that vision
- Suggest how research developments will lead to progress toward that vision
- Suggest where international cooperation is needed to accelerate developments
- Identify impediments, hindrances, and stumbling blocks to international cooperation
- Identify policy, support, outreach, and promotion opportunities
- Determine recommendations/open questions

Background

- The smart grid and storage 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 material 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.

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

CO2 abatement potential of 0.9-2.2 Gt/year by 2050



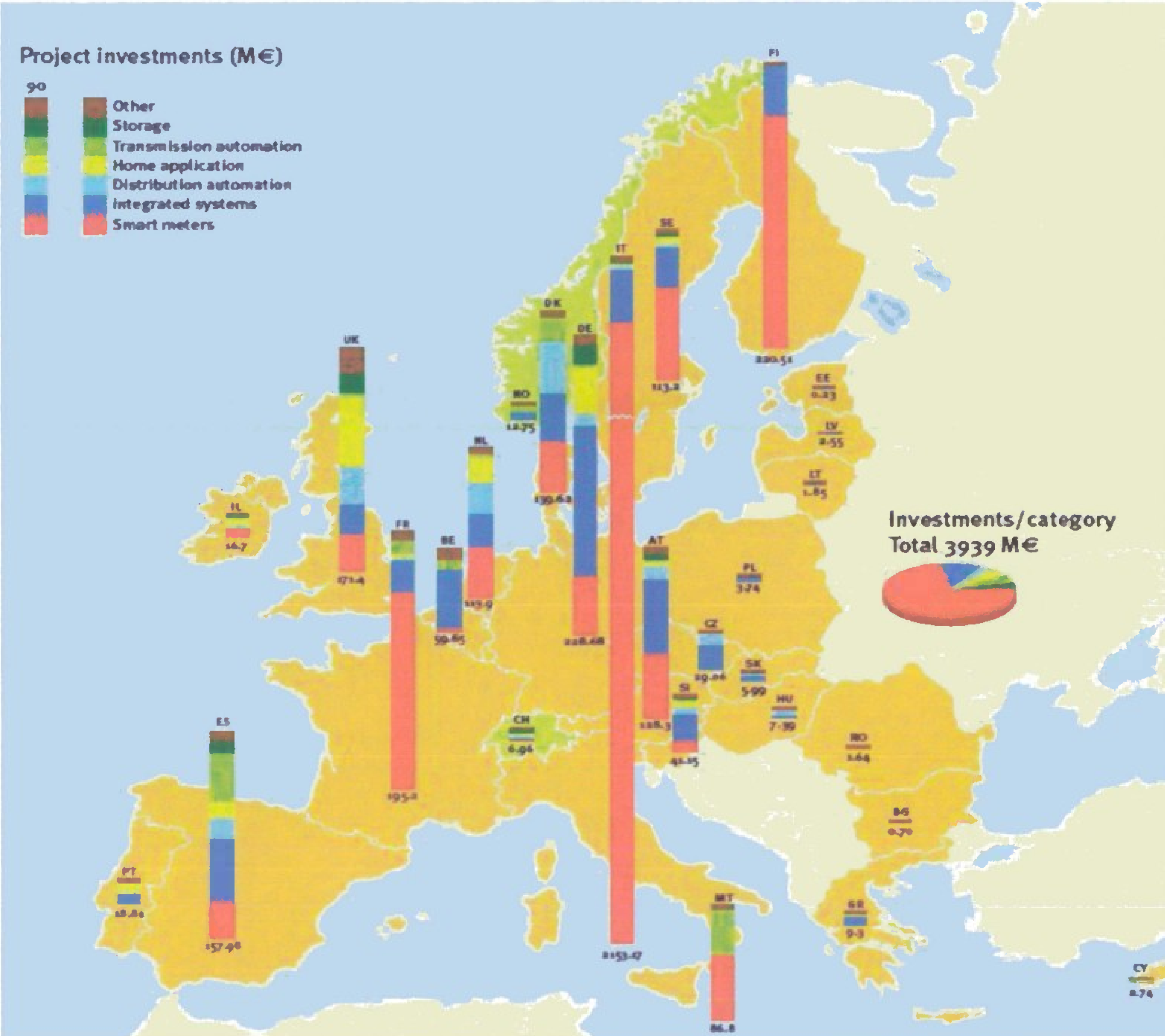
Slide contents: courtesy of IEA

Smart Grids have the potential to reduce global CO_2 emissions by over 2 gigatonnes per year by 2050

Current state of the technology (Bird's eye view)

Description and scope of the technology

- viable technologies are already available for smart grid sensors, communications and control
- amorphous core and nano-crystalline energy saving materials will have a large role to play
- in the case of storage the costs are high and deployment is low; compressed air is the most cost -effective for bulk energy storage but has site-specificity challenges; pumped-hydro storage is the most mature; flywheels can be viable for short-term storage
- most other technologies are longer term prospects

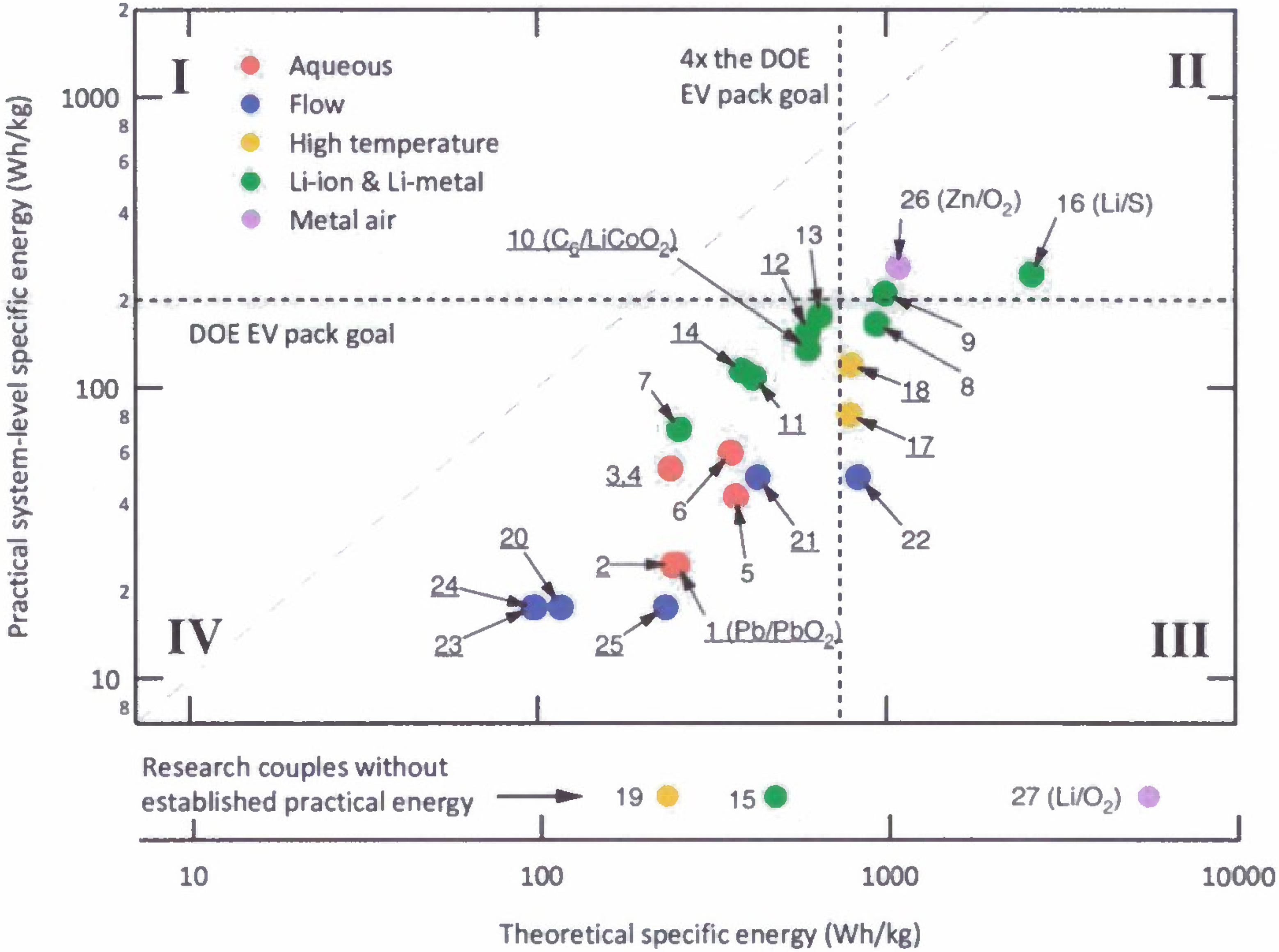


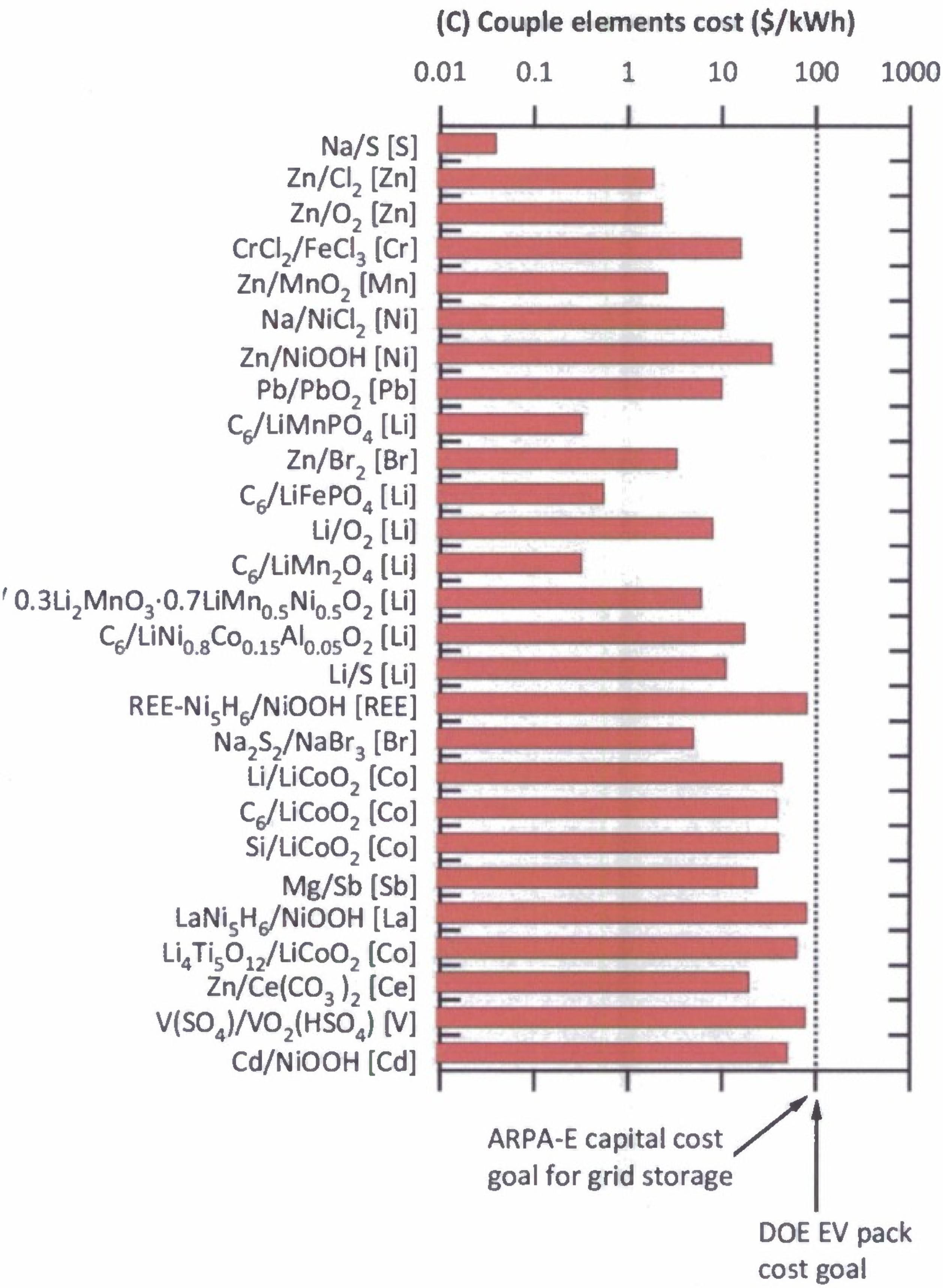
SG investment is happening now: e.g. €4bn in EU

Current directions and rates of change of the technology

- For storage: low learning rates for compressed air and pumped storage; moderate for batteries; medium for thermal storage
- For transmission there's a trend towards: DC cables, super high voltage transmission, ground cables, carbon fibre reinforced cores in overhead cables;
- longer term cable materials research needs include: high temp super conductors; smart materials to mitigate natural risks; heat and flame resistant polymer materials
- EV and hybrids are of growing importance because of the link with rechargeable stations and off-peak charging to levelise loads
- Other major elements and their related materials foci include: power electronics, smart meters, intelligent networks at the end-user site level and end-use interfaces

Batteries *Schmatteries*





Batteries Schmatteries

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

Current state of the technology (Bird's eye view)

Current "best," i.e. most promising and best-developed options

- For storage: compressed air is cheapest for large scale site issues permitting; pumped hydro most developed but site constrained; batteries and fuel production (hydrogen) have high research development opportunities for material science; fly wheels have a role for short term storage
- For transmission cables: trend towards DC and super high voltage transmission; also ground cables; carbon fibre reinforced core for overhead cables; longer term research needs include: high temp super conductors; smart materials to mitigate natural risks; heat and flame resistant polymer materials
- RE sources are key element in smart grid; fuel cells for distributed generation

Strengths and weaknesses in the science and technology (core competencies and gaps)

- There are a significant number of technology assessments of both the smart grid and energy storage that can be used (IEEE, APS, CRS, Sandia others – these are U.S. centric, so international perspective would be useful.
- There is an important gap in the matching of material science technologies with market applications

Long-term vision or goal (toward 2030)

Relevant existing roadmaps and their time horizons

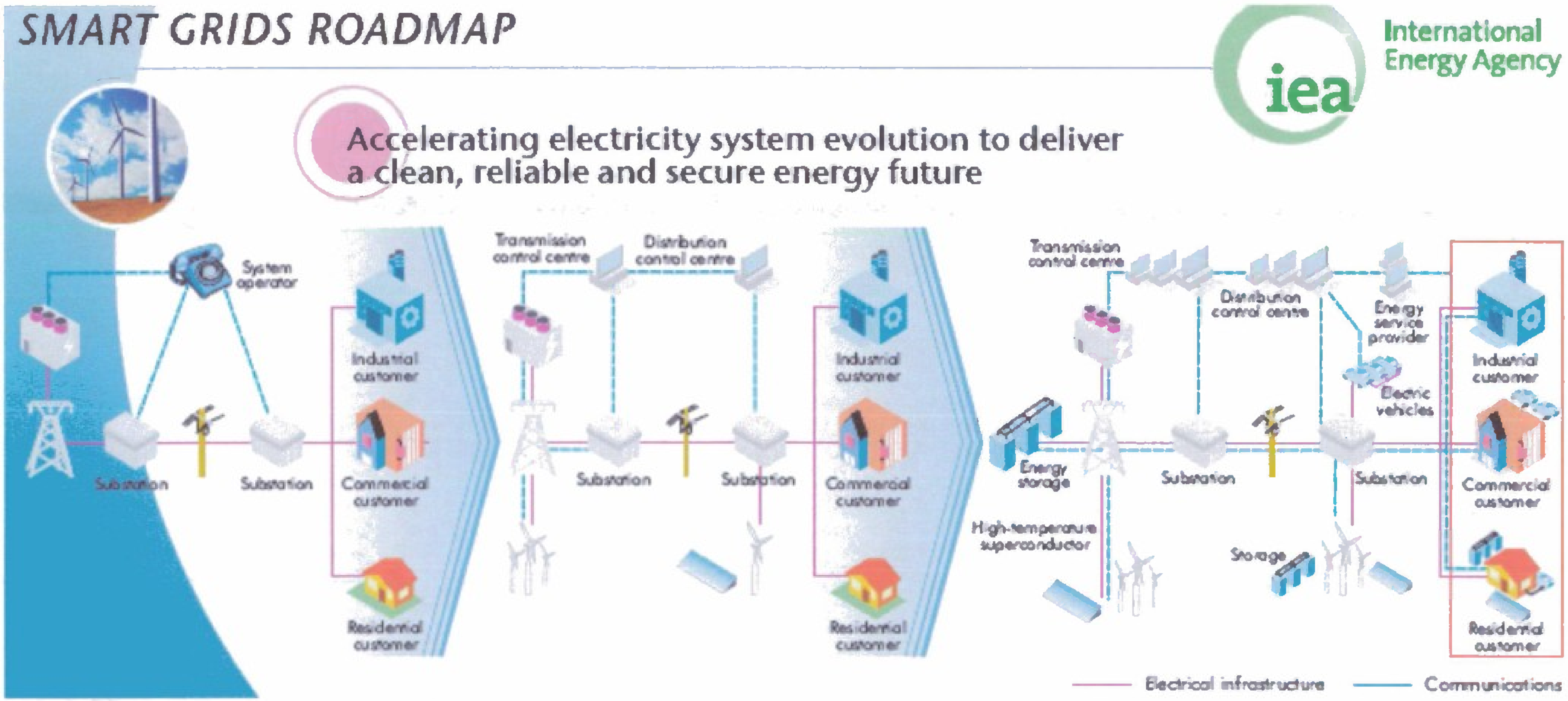
- Regional: EU-DESERTEC, DOE, Chinese plan etc
- International: Clean Energy Ministerial -International Smart Grid Action Network;

Need for new or modified roadmaps –

- the need is for progressive development of the existing road maps
- Its realistic that some of the regional smart-grid road maps could be deployed within the 2025-50 timeframe; worldwide development will be longer term
- Many micro-challenges exist within these and these are where material science has a role. e.g. in the US there are ARPA-E goals for $100/kWh for system storage, and other policy goals for smart grid infrastructure and storage deployment)

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

Many SG road-maps exist



Slide contents: courtesy of IEA

US DOE storage technology road-map

FIGURE 1: PRIORITIZED ACTIVITIES TO ADVANCE ENERGY STORAGE TECHNOLOGIES

	NEAR TERM (< 5 years)	MID TERM (5–10 years)	LONG TERM (10–20 years)
ADVANCED LEAD-ACID AND LEAD-CARBON BATTERIES	Conduct DOE-funded validation tests of system lifetime, ramp rates, etc. Develop high-power/energy carbon electrode for lead-carbon battery	Understand poor materials utilization through diagnostics and modeling	
LITHIUM-ION BATTERIES		Develop models for ion transport through solids (inorganic solids, polymers) Conduct experiments to develop a quantitative understanding of catastrophic cell failure and degradation Design and fabricate novel electrode architectures to include electrolyte access to redox active material and short ion and electron diffusion paths (e.g., non-planar geometries) Develop a highly conductive, inorganic, solid-state conductor for solid-state Li-ion batteries	Develop new intercalation compounds with low cycling strain and fatigue; aim for 10,000 cycles at 80% depth of discharge
SODIUM-BASED BATTERIES	Develop robust planar electrolytes to reduce stack size and resistance Implement pilot-scale testing of battery systems to develop performance parameters for grid applications	Decrease operating temperature, preferably to ambient temperature	Develop a true sodium-air battery that provides the highest value in almost any category of performance Use surface-science techniques to identify species on sodium-ion anodes and cathodes

	NEAR TERM (< 5 years)	MID TERM (5–10 years)	LONG TERM (10–20 years)
FLOW BATTERIES	Establish a center for stack design and manufacturing methods, including joint and seal design Develop low-cost, formable, chemically and thermally tolerant resins for piping, stacks, and tanks Develop an inline, real-time sensor that can detect impurities in electrolyte composition for various flow battery chemistries Create a computational fluidics center at a national laboratory or university Identify low-cost hydrogen suppression materials (anti-catalysts) and redox catalysts for negative electrodes	Improve membranes to enable minimum crossover, lower system cost, increased stability, and reduced resistance Improve mass transport via a tailored catalyst layer and flow field configurations to increase operating current density and reduce system cost per kilowatt	Develop non-aqueous flow battery systems with wider cell operating voltages to improve efficiency
POWER TECHNOLOGIES	Develop a 1-megawatt flywheel motor capable of vacuum operation and superconduction Develop high-power/energy carbon electrode for electrochemical capacitors	Optimize materials utilization through diagnostics and modeling Develop hubless flywheel rotor with four times higher energy	
EMERGING TECHNOLOGIES		Improve thermal management in endothermic electrolysis reactions and exothermic fuel cell reactions in regenerative fuel cells	Develop new catalysts for metal-air batteries with low overpotentials for oxygen reduction in order to make systems more efficient, cost-effective, and bifunctional Explore the untapped potential of multivalent chemistries Develop air electrodes for metal-air batteries with high electrochemical activity and lower polarization and resistance
CROSSCUTTING ACTIVITIES	Combine technologies for synergy Conduct DOE-funded demonstrations of all energy storage technologies Specify cycle and life tests for stationary power applications	Take an integrated approach to degradation by combining microstructure/chemistry observations with mechanistic modeling (both degradation and electrochemical models) and accelerated testing	

Major research and technological needs and opportunities in support of vision

Current limitations to achieving goals

- Storage energy densities are too low for mobile applications and prices are too high
- For smart-grid the primary barriers are policy, market and organisational in nature; technology limitations are secondary

Ways to overcome/bypass such limitations

- Governmental and industrial partnerships; common visions; new business models

Main challenges

- Material science community is not sufficiently involved in the discussions about SG development

Connection of research developments to achieving vision/goals

- How will materials science developments close technological gaps?
- Several technology issues are *fundamentally* materials issues (storage, transmission)
- How will end results affect societal development, resource use, emissions, waste, security?
- Key point is smart grid is not an end to itself but enables certain technologies (DG, RE, etc. Storage does not produce energy, indeed it is a net consumer)

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

E-MRS C-MRS

Major research and technological needs and opportunities in support of vision

- Limitations include technology, but also communication, education and outreach regarding the benefits and importance of a smarter grid
- Existing assessments will help however –
  - Storage represents a disparate set of technologies so a uniform technology assessment and prioritization is somewhat challenging

Opportunities for international cooperation to accelerate developments in this field

- WHY & WHERE are there international cooperation needs
  - Tools
  - Scale
  - Critical players
  - Benefits to these technologies {whole > Σ(parts)}

- Mechanisms to stimulate cooperation
  - Who/what (type, specialty, size) should be involved
  - How people/organizations should be involved?
  - Funding
  - How to involve less developed and developing countries/regions and emerging economies

Opportunities for international cooperation to accelerate developments in this field

- Well developed international organizations on smart grid
- Less on grid storage. Tend to be technology centric by discipline
- Some international organizations/conferences (EESAT, ESA)

Impediments/hindrances/stumbling blocks to international cooperation

- Major factors that slow progress in this field
- Possible means to minimize/eliminate them
- Potential cost to the field/technologies if there is no international collaboration

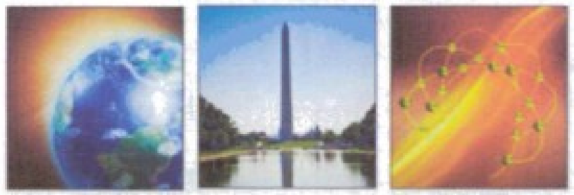
MRS MATERIALS RESEARCH SOCIETY Advancing materials. Improving the quality of life.

Concluding/summary slide

Recommendations

- Material Science community needs to follow and aim to be present at the discussions on SG development to ensure that its role is understood and to better plan its input

2011 World Materials Summit



Vehicle and Transport (Cars, Buses)

MRS MATERIALS RESEARCH SOCIETY E-MRS C-MRS

MRS MATERIALS RESEARCH SOCIETY
Advancing materials. Improving the quality of life.
E-MRS
C-MRS

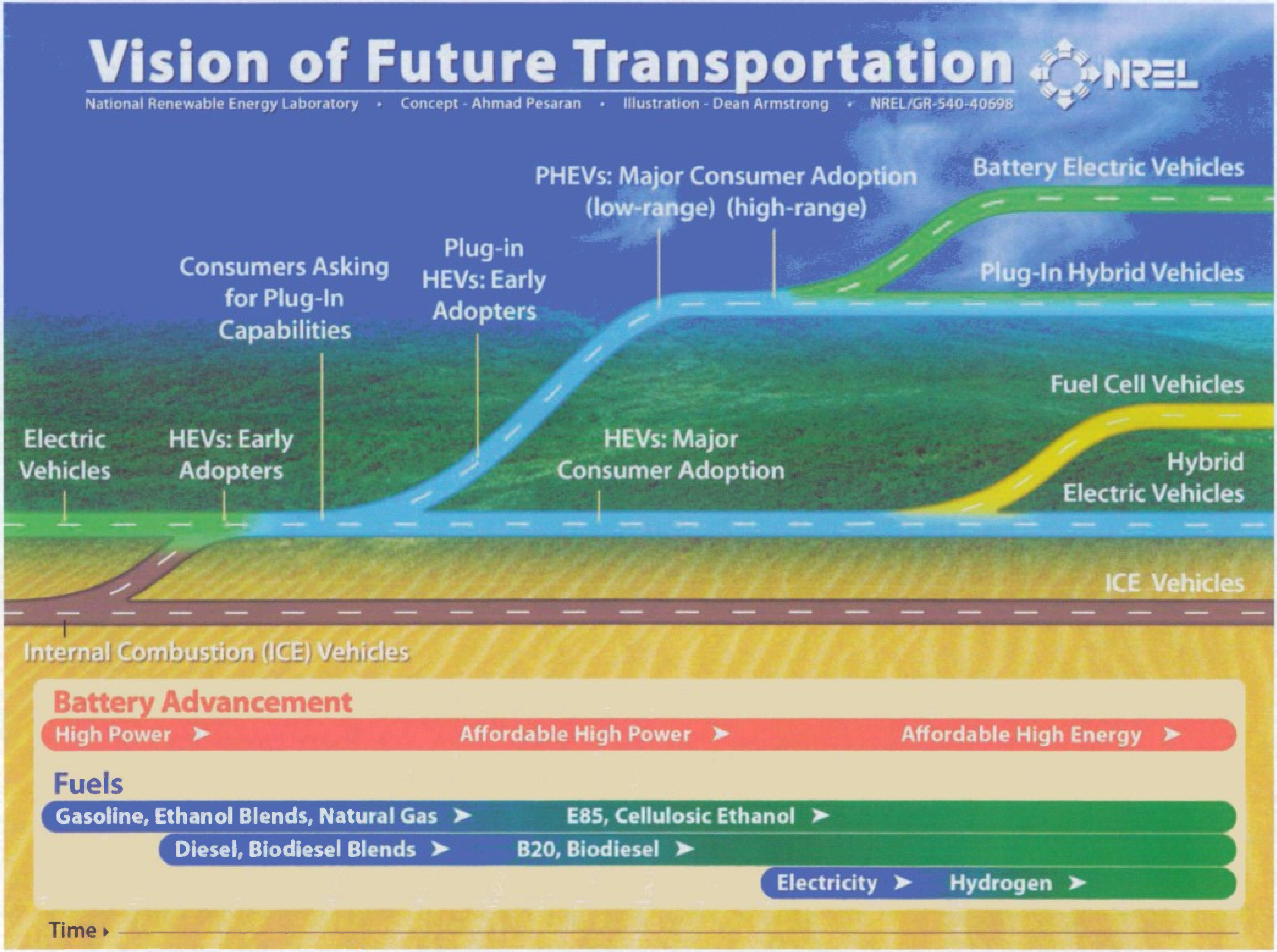
Report of the Vehicles and Transportation Panel

Chairs

Bernard Frois and Yusheng Zhao

- Current and Future Technologies
- Vision 2030
- Roadblocks
- Recommendations

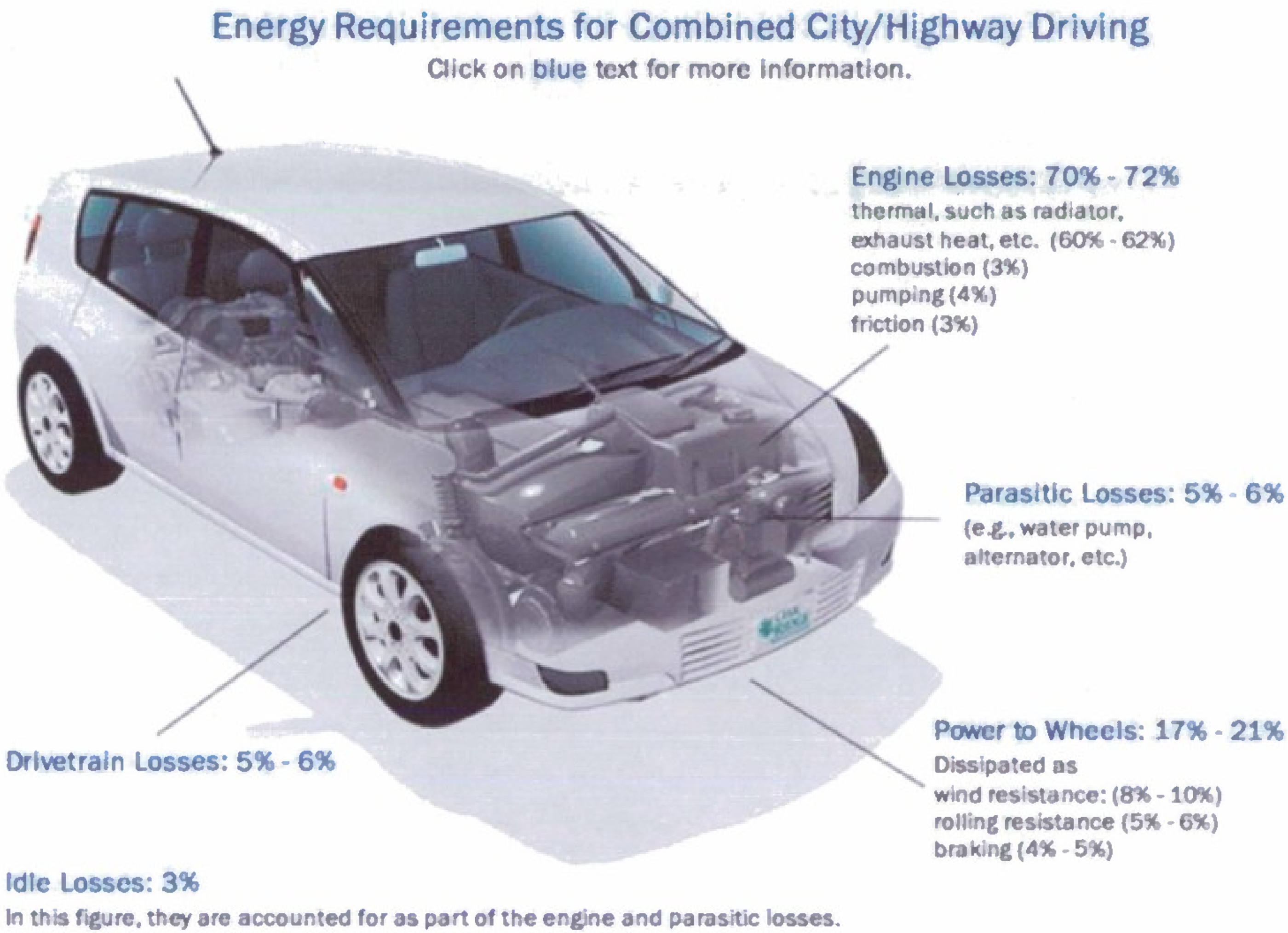
2011 World Materials Summit



Vision of Future Transportation
NREL
National Renewable Energy Laboratory • Concept - Ahmad Pesaran • Illustration - Dean Armstrong • NREL/GR-540-40698
Battery Electric Vehicles
PHEVs: Major Consumer Adoption
(low-range) (high-range)
Plug-In Hybrid Vehicles
Consumers Asking for Plug-In Capabilities
Plug-in HEVs: Early Adopters
Fuel Cell Vehicles
Electric Vehicles
HEVs: Early Adopters
HEVs: Major Consumer Adoption
Hybrid Electric Vehicles
ICE Vehicles
Internal Combustion (ICE) Vehicles
Battery Advancement
High Power
Affordable High Power
Affordable High Energy
Fuels
Gasoline, Ethanol Blends, Natural Gas
E85, Cellulosic Ethanol
Diesel, Biodiesel Blends
B20, Biodiesel
Electricity
Hydrogen
Time

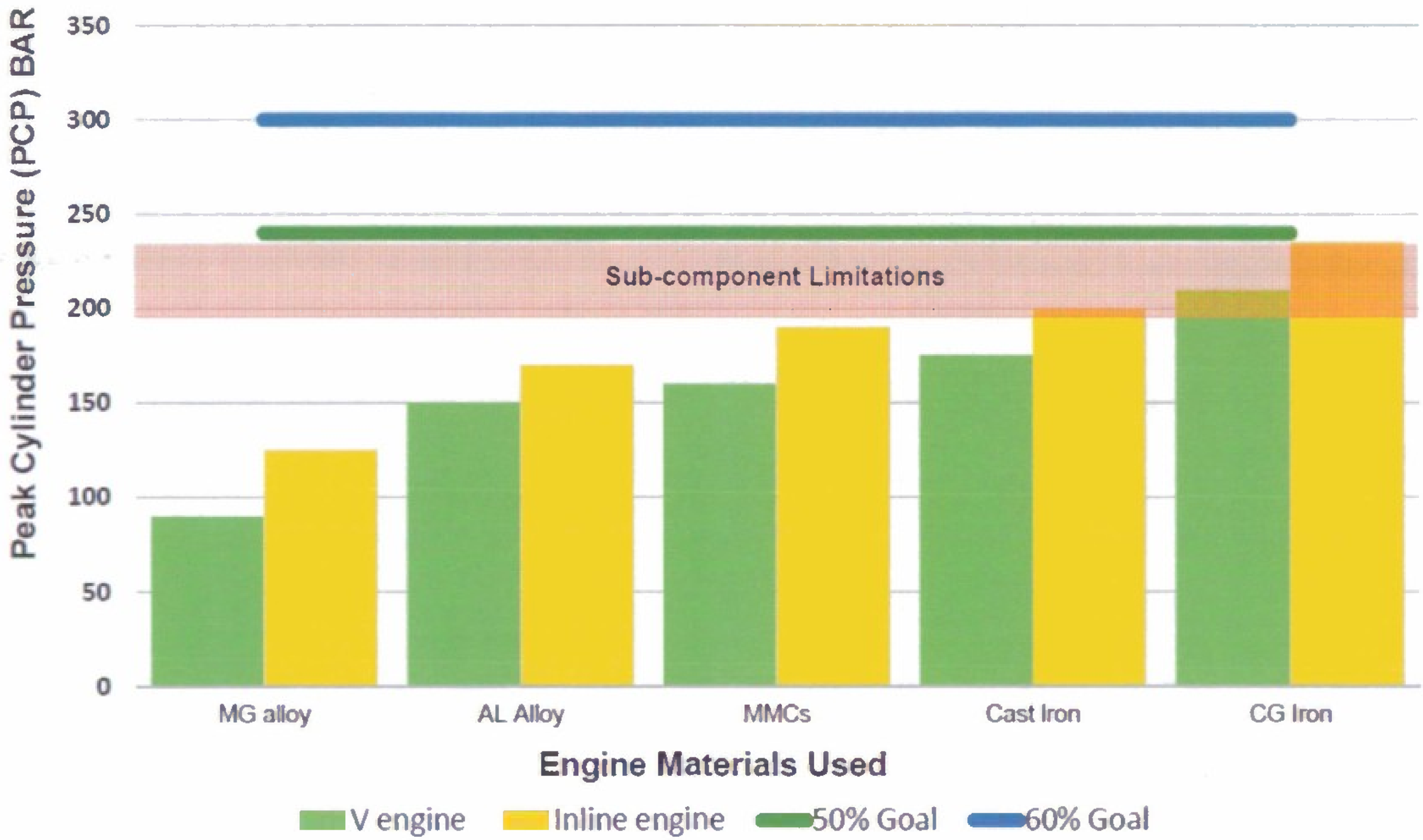
MATERIALS RESEARCH SOCIETY
Advancing materials. Improving the quality of life.

Only about 15% of the fuel consumed is actually used to propel the vehicle and support the accessory loads.



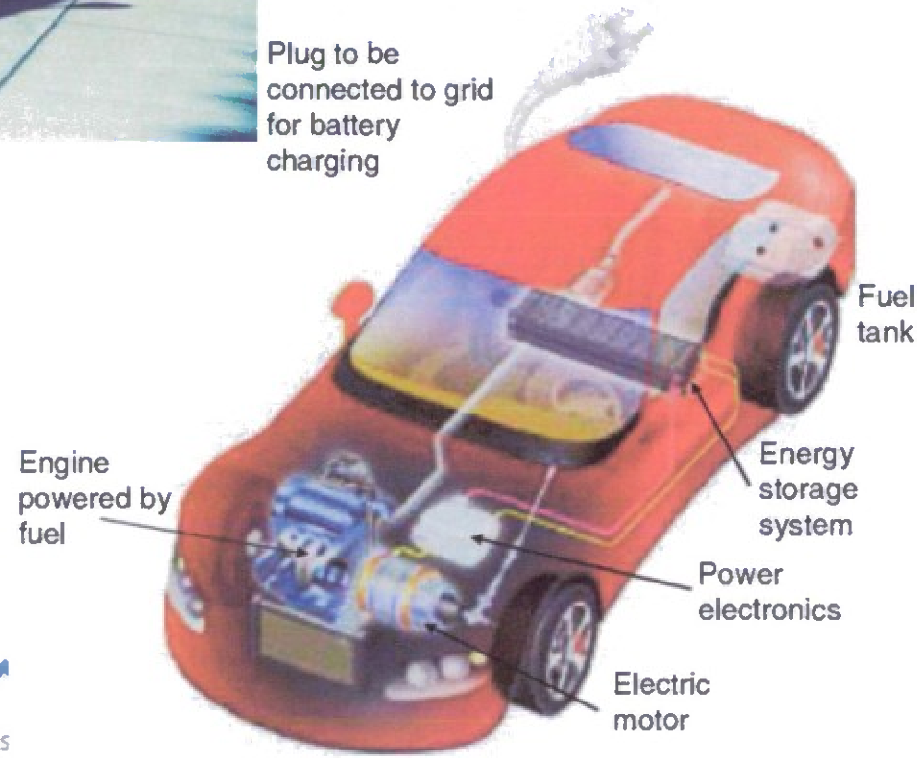
Current Material Limits

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



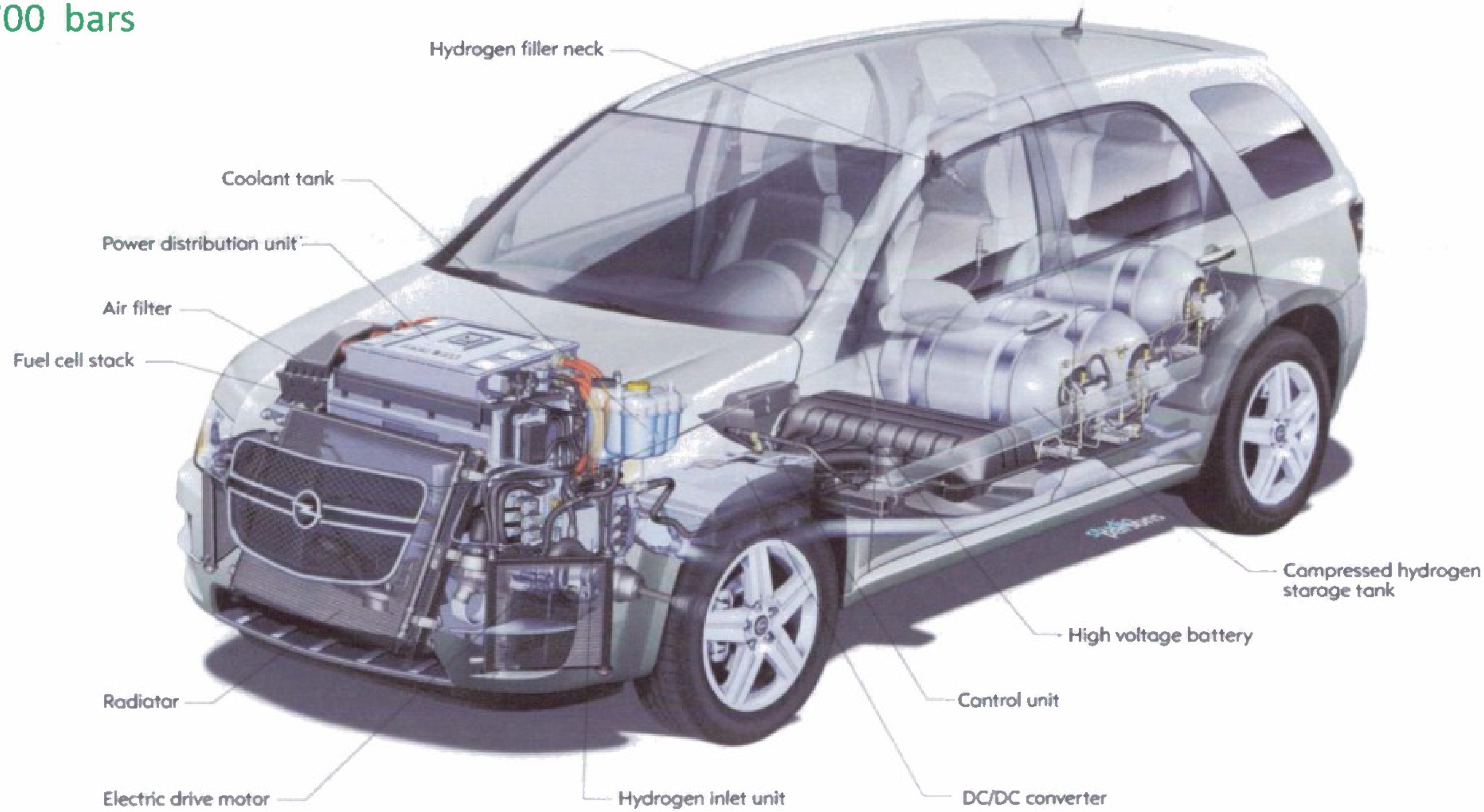
Based on 1999 study


F GG 9050


Plug to be connected to grid for battery charging
Fuel tank
Energy storage system
Power electronics
Electric motor
Engine powered by fuel

93 kW
320 km
12s
160km/h
700 bars

OPEL (GM) Hydrogen4



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

Vision 2030

- **De-carbonization of transport**
- **Smart road, smart car, smart networking**
- Durability and long-term reliability of batteries,
- Sustainability
- Economical
- Market deployment of high efficiency cars

2011 World Materials Summit

Developments towards Vision 2030

- High efficiency ICE: decrease fuel consumption
- High energy density and high power capacity batteries
- Fuel cell: cheap catalyzers, better membrane,
- Reduce weight by using composite materials
- Optimization of power management systems
- Sensors and real-time information
- IT networking

International Collaboration

– Facilitate scientific exchanges
– Develop an agreement on long term vision.
– Share concepts and best practices
– Agree on codes and standards
– Focus on technological research and technology transfer

Roadblocks

- Competition slows information flow of exchange
- Patents and IP protection prevent technology transfer
- Public acceptance may delays market deployment
- Long term availability of materials
- Access to strategic materials (REE, Li, Rubber, Transition Metals,

Policy, Industry, Outreach and Education

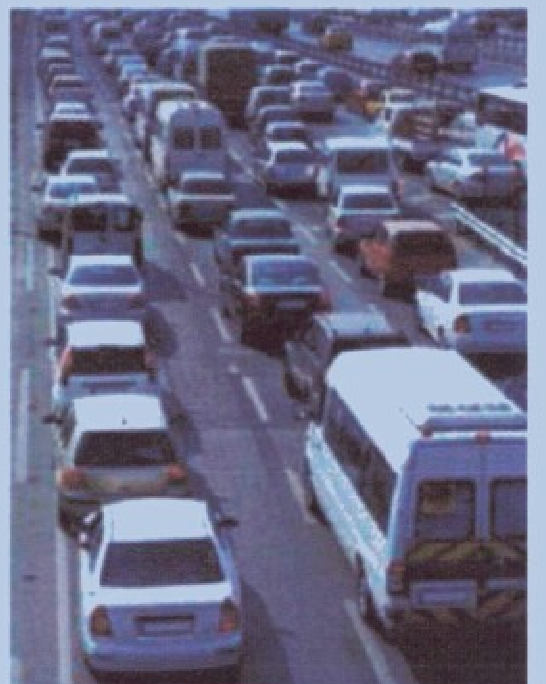
- National/Central government policy
- Regional/Local policy development
- Industry should be involved at early stage
- Regulations and standards
- Risks and liabilities
- Incentives
- Public awareness and involvement
- Education and training of next generation of scientists and engineers

Recommendations

- **Expand dialogue with policymakers and Industry**
- **Develop road map** and update it every two year in Summit
- Study specifics of buses and trucks (heavy duty vehicles)
- Link with aircraft industrial needs, battery and fuel cell
- Analyze materials needs for high speed train
- Develop new architectures in power electronics (powertrain management). Link with Intelligent technologies

ENERGY

SOCIETAL CHALLENGES



De-carbonisation of transport

the case of the electric vehicle

The Challenge of Water

- Panel
  - David Cahill (U. Illinois, WaterCAMPWS)
  - Xie Quan (Dailan University of Technology)
  - Martin Green (NIST)
  - Duan Weng (Tsingua University)

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

Current State of Technology

- Water purification
  - Purify source waters for food production, human use, energy, and industry.
  - coagulation, filtration, chlorine-based disinfection, desalination of seawater and brackish water
- Water treatment
  - Treat waste streams from food production, human use, energy, and industry.
  - Biological processes, filtration, membrane separations, oxidation, adsorption, disinfection

Current State of Technology

- Common trends
  - Increased use of membrane processes in both water purification (desalination) and treatment of waste (water recycling)
  - Increased use of advanced oxidation for low-level toxic contaminants and disinfection (O_3, H_2O_2)

Long term vision and goals

- Increase H_2O supplies where and when they are needed through efficient purification of impaired water.
- Detect and selectively remove low-levels of toxic contaminants at low cost.
- Disinfect without producing toxic by-products.
- Develop low-cost, robust systems with minimal energy and chemical inputs that can be deployed world-wide.

Materials Research Needs

- Multi-functional materials
  - Membranes that separate and disinfect
  - Adsorption/catalytic materials that concentrate and destroy organic contaminants

Materials Research Needs

- Membranes
  - Capability to rapidly develop and deploy application-specific membranes for both centralized and point-of-use systems.
  - Chlorine tolerant membranes for reverse-osmosis, nanofiltration, and forward-osmosis.
  - Membranes resistant to bio-fouling and scaling.
  - Improved rejection of neutral small molecules (B, As-containing species).

Materials Research Needs

- Detection and destruction of low-level toxic contaminants
  - Sensor materials and systems that are sensitive, selective, and long-lived in natural water and waste streams.
  - Closed-loop sensor/purification systems.
  - Remotely powered, on-line, portable sensing.
  - Catalytic and photocatalytic materials for advanced oxidation of organic micro-pollutants.

Materials Research Needs

- Disinfection (particularly in non-industrialized regions)
  - Materials that enable sunlight-driven disinfection (or if not sunlight then high-efficiency UV LEDs powered by photovoltaics).
  - Low pressure membranes that can be easily cleaned and capable of removing viruses

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

Materials Research Needs

- Basic research challenges
  - Incomplete molecular-level understanding of membrane separations.
    - No one can separately measure or predict the partition coefficient and mobility of a contaminant.
    - No one can quantitatively connect molecular structure to water permeability.
  - Incomplete understanding of mechanisms of oxidation and disinfection by photocatalysts.
- Gaps in basic understanding impair our ability to design new materials for specific applications.

International Cooperation

- As with energy, water is an international problem. Energy use is growing; water use will grow too.
- Water crosses national boundaries and will increasingly become a cause of conflict between nations.

MRS MATERIALS RESEARCH SOCIETY Advancing materials. Improving the quality of life. E-MRS CMRS

International Cooperation

- International, cooperative research on materials for water purification/treatment is very limited compared to the scope of the problem we face.
  - China with Japan (JST and JSPS funding) and Korea on water treatment technologies.
  - China with EU on basic science of pollution of surface waters.
  - US with Saudi Arabia (KAUST) on desalination

Impediments to Int. Cooperation

- At least in the US, overall funding is small and little additional funding is available for international cooperative research
- US has much to gain from other countries who have invested heavily in water research and are facing severe problems sooner-rather-than-later
  - China, Israel, Singapore, Saudi Arabia, Spain, Netherlands

International Cooperation

- Industry has to be involved. Research universities cannot deploy materials on the scale needed in water purification and treatment. Cost is an overriding issue.
  - Waste water treatment in US and China totals 10^{11} m^3 per year.

Outreach

- Raise public awareness of the value of water.
  - Source protection
- Education on health and safety of water sources. Water should be recycled too.

2011 World Materials Summit

Advocacy, Outreach, and Policy

Advocacy

- Students have a responsibility to be advocates
  - All of us must be advocates
  - We must lead by example in lifestyle and research
    - Recycling in our labs and homes
    - Pay attention to energy efficiency
    - Develop a document for the "green scientist". Guidelines on how to conduct environmentally friendly research and pay attention to impacts.
    - Ideally, this should to be taken into account in the judgment of proposals grants
  - There is much we can do which is low cost but large impact
  - TALK TO PEOPLE

Reaching Leaders

- We need the power to change things quickly, world leaders can do this.
- Continental Committee
  - A committee of international people representing us all, empowered to present ideas from this summit over the next 2 years to organized bodies like the UN, AU, EU, etc.
  - Report to MRS and next WMS, effecting change
  - Learn how to deliver key information to politicians and decision makers
- Changing perceptions will eventually change how people vote and eventually change politics.

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

Reaching the Public

- Grassroots change from the bottom up
- Targeted information and initiatives to local populations that provide positive messages in vernacular and simple solutions relevant to daily life:
  - MRS ambassadors through volunteerism in local schools, providing resources for what they might talk about for different age groups
  - Use Social Media and Networks
  - Text Messaging
- Change the perception of scientists and science so we are viewed in a positive light.
- Make science relevant to everyone's daily life.
- Widespread publications in language everyone can understand

Policy

- Formalized environmental education is key. We need funding for education.
- Enforcement is key. Governments must make sure that environmental rules are followed and loopholes are closed.
- Make public service announcements.
- Initiatives for efficiency and conservation
  - Subsidies and products to help people be more environmentally friendly and change habits.

Feedback

- Self-evaluation at next WMS:
  - Report from the Continental Committee to connect this conference to the next conference and assess our progress.
- Communication with Communities
  - Formally survey the population and involve them in the process
  - Collect feedback from local people on what they think works and on how our methods could be improved
- Feedback from policy makers

Our Group Members

Maria Eugenia Perez
Ana Lia Noguera
Ivana Aguiar
Jagadeesh Babu Bellam
Maria Kandyla
Jenny G. Vitillo
Agnieszka Lekawa-Raus
Gusphyl A. Justin
Stella Itzhakov
Lauren Klein
Elsa Callini
Bright Sogbey
Janet Bamgbose
Ying Ma

Education and International Collaboration

Ivana Aguiar
Ratna Kumar Annabattula
Ndigui Billong
He-yun Du
Jianying Ji
Agnieszka Lekawa-Raus
Maria Eugenia Perez
Mohammad Ali Rafiee
Daniel P. Shoemaker
Bright Sogbey
Antonio Vicente
Jenny G. Vitillo

Education

Consider the cases of global warming and renewable energy: sustainable consumption is not a serious concern for the general public

For the youth: Teach that energy is precious. Encourage daily action, curiosity

Even when aware of the problem, educators do not have the tools to explain or demonstrate energy-related problems

To aid instruction at all levels, create a knowledge base containing lecture materials and demonstrations

A typical materials curriculum is not focused on integrated solutions to global problems that extend beyond technical development

Create adaptive curricula to address sustainability and interdisciplinary studies, attract talented students who will, in turn, help produce educational modules

International Collaboration and Exchange

For members of the energy materials community, information such as:

Educational modules
Outreach
Intellectual property rights
Opportunities for funding, two-way foreign exchange

is not organized or distributed efficiently

All of this information can be organized in a centralized, online knowledge base

MRS has already started this! It must be made explicit, improved, larger, easily accessible and open to expansion in local chapters.

Organization should advertise and provide a virtual center for opportunities in international exchange

Recommendations

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

Create a central database of research and travel funding, institutes willing to collaborate, and relevant workshops and conferences.

Create an active social network of student congress participants. Share ideas and successes. How are we making a difference?

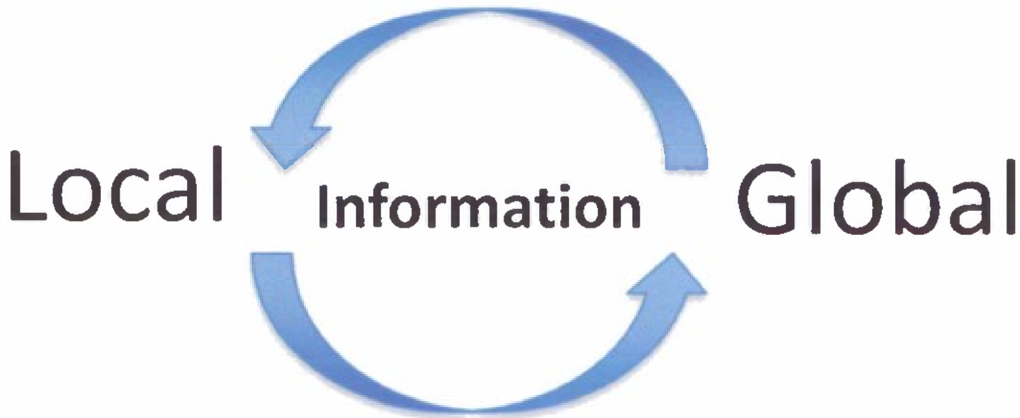
2011 World Materials Summit

Panel Discussion Energy

Mario Michan, Nicolas Woehrl, Marina Mariano, Nour Nijem, Alfred Chidembo, Isaac Tamblyn, Manoj Ramachandran, Araceli Rios, Ingadeesh Babu Bellam, Xin Wang, Yu Liu, Meng-Qi Zhou,

Motivation

- Each region has different resources and technological needs for energy production
  - Different priorities
- Decisions on energy will ultimately be made locally but will have a global impact
- Information needs to be globally shared



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

How can we proceed?

- This calls for **diversity** in both research and deployment of solutions, on different timescales

- The materials community should inform the global community of the technological options with **unbiased data** and evaluation metrics (e.g. greenhouse gas emissions, lifetime cycle analysis, etc)

How can we proceed?

- The Material Societies can improve the information flow
  - The society should provide better information based on the following internationally agreed on metrics:
    - GHG emissions (actual, potential reductions)
    - Lifecycle analysis (LCA)
    - Risk assessment and reduction
    - Region specific assessments of potential technologies
  - MRS should facilitate the creation of the **standards** of these **metrics** so we can all report and make decisions based on those metrics

Key Statement

- Provide unbiased reporting and analysis of energy technologies based on standardized sustainability metrics such as:
  - GHG emissions (actual, potential reductions)
  - Lifecycle analysis
  - Risk assessment and reduction
  - Region specific assessments of potential technologies

2011 World Materials Summit

Markets and Economics

Ian Murray, Isaac Tamblyn, Antonio Vicente, Gusphyl Justin, Stella Itzhakov, Marina Mariano, Nicolas Woehrl, He yun Du, Ana Lia Noguera, Ndigui Billong

Global Imbalances

- R&D vs. Manufacturing
- Artificial Market Imbalance due to Externalities
- Natural Resource Availability
- Monetary Resources
- Locality of Problems and Capacity to Solve Them

Understand and Address Imbalances

- Scientific education requires economics
- Additional investment in translating research into products
  - Goal-based prizes for critical technologies (X-prize)
  - Materials-centric business plan competitions
  - Graduate exchanges with companies
  - Increase grants for early stage commercialization
- Communication of technology gaps in developing countries to researchers

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

Reporting to Address Imbalances

- Increase funding to quantify real costs associated with different energy sources
- Comprehensive reporting of govt. investment
  - R&D vs. manufacturing incentives
  - Clean technology share of R&D
  - Quantify research efficiency
- International targets for key research metrics
  - UN or WTO?

Small and Developing Countries

- Communicate local needs to global research community
  - Competitions to solve humanitarian challenges
- Open access to journals / information
  - i.e. www.arxiv.org
- Assisting business growth in small markets
  - Subsidized licensing of relevant patents

Global Research Funds for Humanity

- Consequences of climate change and resource issues are shared globally
- Multinational funding of research to improve clean energy and water technologies
  - Advances shared globally

Recommendation

- 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.

Water

H—O—H

Hongmei Du, Yu Lu, Deniz Wong, Mingshan Wang, Huadong Fu, Enock Dare, Bin Li, Maria Kandyla, Sun-Tang Chang, He-Yun Du, Gusphyl Justin, Meiling Wu, Ming Wang, Mengqi Zhou, Xin Wang, Antonio Vicente, Kayvan Rafiee

2011 World Materials Student Congress

There are technological, economical and governmental challenges associated with water

Valuing water

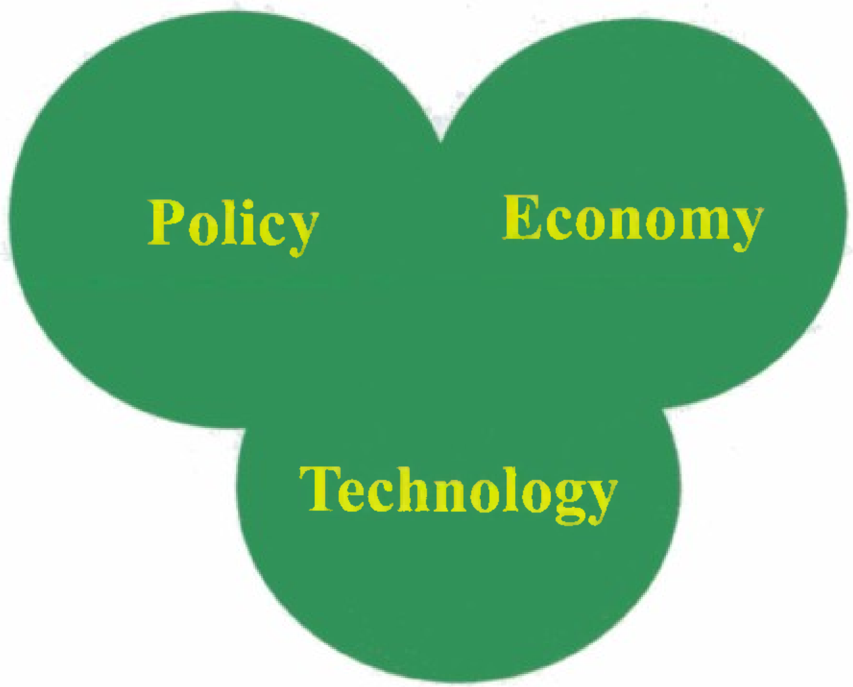
Governing wisely

Sharing water resources

Water & Industry

Water & Energy

Ecosystem



Pollution and purification

Water relocation

Distribution systems

Suggestions

- Creative leaders for economical development (education)
- Build the culture of efficient water consumption (education)
- International standards for waste management systems and pollutions
- Investment on technological innovation in purification and pollution

Recommendation

To develop appropriate technologies, educational awareness, and standards to encourage efficient water purification, management and access for a growing world population.

Thank you & Comments

Hongmei Du
Yu Lu
Mingshan Wang
Huadong Fu
Enock Dare
Bin Li
Maria Kandyla
Antonio Vicente
Deniz Wong

Maria Kandyla
Sun-Tang Chang
He-Yun Du
Gusphyl Justin
Meiling Wu
Ming Wang
Mengqi Zhou
Xin Wang
Kayvan Rafiee

Contact:
Kayvan Rafiee rafiee@rpi.edu
Deniz Wong denizpwong@yahoo.com