Clean energy and sustainability are global issues that require international collaboration. Materials play a critical role in addressing these challenges. The Second World Materials Summit in Suzhou provides an avenue to create international cooperation to address energy-related materials solutions. Our priorities track the relevant sections of the Kyoto resolution.

From these we resolve in a timely fashion to:

1. Seek alignment among international energy materials strategic plans with the goal to identify common global needs.
2. Implement programmatic and communication initiatives to address item 1.
3. Promote the education of a new generation of international scientists, engineers and leaders for leveraging materials science and technology for energy research and development and to provide a clear picture of the challenge, opportunities and career path.
4. Encourage funding agencies to develop initiatives to allow major international collaborative materials research programs on energy.
5. Provide technical expertise and information to global, regional and national policy makers, industry and investors in materials for energy research and innovation.
6. Partner with key international organizations relevant to the energy sector to further the above programmatic initiatives.
7. Stimulate public interest worldwide in, and awareness of the significance and challenges of energy-related issues.

The World Materials Summit at Suzhou in October 2009 collected scientific and technical reports and made recommendations on how to best achieve the essential acceleration of development by the worldwide materials science and technology community.
Program

Second World Materials Summit
Shilla Hotel, Suzhou

Monday, Oct. 12, 2009

08:00-22:00 Registration (Lobby, Shilla Hotel)
09:00-12:00 Cultural Event (Suzhou Garden)
12:00-13:30 Lunch
14:00-17:00 Technical Visit (Suzhou Industrial Park)
17:30-19:00 Welcome Reception

Chairs: Duan WENG, Qiang FENG

Welcome Speech: Leader of Suzhou Industrial Park

Guest Speeches:
B.V.R. CHOWDARI, First Vice-President of IUMRS and President of MRS-S
David GINLEY, Vice-President of MRS
Naoki KISHIMOTO, President of MRS-J
Jean Pierre PIERRAT, Scientific Attaché, French Consulate Shanghai

19:30-21:10 Plenary Session I

Chairs: Hongjie LUO, Abdelilah SLAOUI

19:30-19:40 Welcome Address: Hailing TU, Vice-President of C-MRS

19:40-20:10 New Materials in the Advanced Powertrains-The Future of VW Electric Vehicles
Jörg HUSLAGE, Research Group Electrical Drives and Fuel Cells, Volkswagen: AG, Wolfsburg, Germany
   Katsuhiko HIROSE, TOYOTA Motor Corporation, Tokyo, Japan

20:40-21:10 Daimler Fuel Cells and the Development of Batteries of the Future
   Florian FINSTERWALDER, Alternative Drives, Production Planning, Technologies and Concepts, Daimler AG, Stuttgart, Germany

Tuesday, Oct. 13, 2009

08:20-09:10 Opening Ceremony

   Chairs: Yong GAN; R.P. H CHANG

08:20-08:30 Introduction of VIP: Yong GAN, President of China Iron and Steel Research Institute Group, China

08:30-08:40 Welcome Address: Kuangdi XU, President of Chinese Academy of Engineering, Chairman of the Summit, China

08:40-08:50 Leader of MOST, China

08:50-08:55 Changxu SHI, Academician of CAS and CAE, China

08:55-09:00 Congbin FU, International Council for Science, Vice President of China Association of Science and Technology, China

09:00-09:05 Boyun HUANG, President of C-MRS

09:05-09:10 Leader of local government

09:10-09:40 Coffee Break and Photography
09:40-11:55  Plenary Session II

*Chairs:* Boyun HUANG, Paul SIFFERT

09:40-10:10  Materials for Efficient Energy Production and Usage
*Raymond Lee ORBACH,* University of Texas at Austin, USA

10:10-10:40  Materials Studies in Low Carbon Energy
*Liquan CHEN,* Institute of Physics, CAS, China

10:40-11:10  Scientific issues for future nuclear energy
*Claude GUET,* Director of the office of the High Commissioner for Atomic Energy, France

*Dan Eliab ARVIZU,* National Renewable Energy Laboratory, USA

11:40-11:55  European Energy Policy and Its Application in Poland
*Krzysztof KURZYDLOWSKI,* University of Warsaw, Poland

12:00-13:30  Lunch

14:00-16:00  Technical Session 1—Solar Energy and Photovoltaic Cell Materials

*Chairs:* Shaoxiong ZHOU, David GINLEY

14:00-14:30  The Future of PV Industry & SG-Si Materials
*Yuwen ZHAO,* China Renewable Energy Society Photovoltaic Sub-society

14:30-15:00  *Martin GREEN,* The University of New South Wales, Australia

15:00-15:30  Advanced Thin Film Materials for Solar Cells: Challenges and Limitations
*Daniel LINCOT,* ENSCP, Paris, France + *Abdelilah SLAOUÍ,* CNRS, Institut d’Électronique du Solide et des Systèmes (INESS), Strasbourg, France
15:30-16:00 Photovoltaic Progress in Taiwan
*Rongchang LIANG+Chorng-Jye HUANG*, Del-Solar Co., Ltd. Taiwan, China

16:00-16:15 Coffee Break

16:15-18:15 Technical Session 2—Nuclear Energy Materials

*Chairs:* Enhou HAN , Alan J. HURD

16:15-16:45 Alan J. HURD+ Cetin Unal, Los Alamos National Laboratory, USA

16:45-17:15 Frédéric SCHUSTER, Materials Program, Commissariat à l’Energie Atomique (CEA), France

17:15-17:45 Choice of Structural Materials for Indian Fast Breeder Reactor Program
*Bhagi Purna Chandra RAO*, India Gandhi Centre for Atomic Research, India

17:45-18:15 Emerging Materials Issues on Materials Safety and Reliability in Pressurized Water Nuclear Reactor
*Enhou HAN*, Institute of Metal Research, China

18:30 Banquet

**Wednesday, Oct. 14, 2009**

08:00-10:00 Technical Session 3—Hydrogen Energy Related Materials and Fuel Cell

*Chair: Lijun JIANG, Mildred DRESSELHAUS*

08:00-08:30 Materials Related to Hydrogen Production and Hydrogen Utilization in Fuel Cell
*Liejin GUO*, Xi’an Jiaotong University, China
08:30-09:00 Materials Challenges for Solid Oxide Fuel Cells
Subhash C. SINGHAL, Pacific Northwest National Laboratory, USA

09:00-09:30 Hydrogen Storage in Nanoporous Materials
Michael HIRSCHER, Max-Planck-Institut für Metallforschung, Germany

09:30-10:00 Hydrogen as a Future Energy Carrier
Andreas ZÜTTEL, EMPA Materials Sciences & Technology, Switzerland

10:00-10:15 Coffee Break

10:15-11:45 Technical Session 4—Large Scale Energy Storage & Batteries

Chairs: Xuejie HUANG, George CRABTREE

10:15-10:45 Progress on Key Materials of Redox Flow Battery for Energy Storage
Huaming ZHANG, Dalian Institute of Chemical Physics, Chinese Academy of Sciences

10:45-11:15 Materials Challenges for Sustainable Energy
George CRABTREE, Argonne National Laboratory

11:15-11:45 Michel ARMAND, University Picardie, France

12:00-13:30 Lunch

14:00-16:00 Technical Session 5—Materials for Bioenergy

Chair: Tianwei TAN, Mike CLEARY

14:00-14:30 Recent Development of Biorefinery in China
Tianwei TAN, Beijing University of Chemical Technology

14:30-15:00 Michael F. CHRISTIANSEN, Novozymes in Asia-Pacific, Denmark
15:00-15:30 State of the Art of Biomass Liquid Fuel in China  
Guojun YUE, COFCO Limited, China

15:30-16:00 Jay KEASLING, The Joint BioEnergy Institute (JBEI)

16:00-16:15 Coffee Break

16:15-17:45 Technical Session 6—Alternative Energy Sources & Transmission

Chairs: Duan WENG, Hanns-Ulrich HABERMEIER

16:15-16:45 Light Weight Vehicles through Advanced Materials  
Robert F. SINGER, University of Erlangen, Germany

16:45-17:15 Development of High Performance Thermoelectric Materials and Devices  
Lidong CHEN, Shanghai Institute of Ceramics, CAS, China

17:15-17:45 Carbon Dioxide a Raw Material for Sustainable Development  
Jacques AMOUROUX, ENSCP, Paris, France

18:00 Dinner

19:00 Night Tour in Suzhou

19:30 Panel Discussion for the Suzhou Declaration 2009

Chairs: R.P.H. CHANG, Dave GINLEY, Yafang HAN, Paul SIFFERT

Participants: B.V.R CHOWDARI, Gabriel CREAN, Mildred DRESSELHAUS, Qiang FENG, Martin GREEN, Katsuhiko HIROSE, Boyun HUANG, Alan J. HURD, Naoki KISHIMOTO, Lijun JIANG, Si-Chen LEE, Jean Pierre MASSUE, Tsong-pyng PERNG, Subhash C. SINGHAL, Francesco PRIOLO, Duan WENG, Osamu YAMAMOTO, Zhaoxiong ZHOU
Thursday, Oct. 15, 2009

08:00-12:00 Round-table Panel Discussion & Report Writing (6 topics)
(Divided into six sessions, organized by chairs of six technical topics, preparing six official technical reports).

12:00 - 13:30 Lunch

14:00 - 15:30 Reporting Back

Chairs: Shaoxiong ZHOU, Gabriel CREAN
(15 minutes for each technical session by one of chairs)

15:30-15:50 Coffee Break

15:50-17:20 Summary Overview, Declaration and Closing

Chairs: Mildred DRESSELHAUS, Francesco PRIOLO

15:50-16:20 Summary Overview: Zakya KAFAFI

16:20-16:50 Declaration: Boyun HUANG

16:50-17:20 Closing Remarks

18:00 Dinner
The World’s energy consumption is approaching 20 Terawatts of which only a small percentage at present is generated by clean, renewable energy. Efficient capture and direct conversion of solar energy into electricity or fuels offers one of the best potential approaches for creating clean energy on a global scale. This panel reviewed and discussed the challenges that need to be addressed for achieving this goal.

Technologies with some current commercial presence but where cost/production/materials may need significant work to achieve the scale of impact desired were mainly discussed. Solar photovoltaics (PV), concentrated solar power (CPV) which is the current description of solar thermal power generation, and concentrated photovoltaics (CPV) which includes multi-junction devices under high concentration, were the focus of the discussion. Some of these technologies are approaching grid parity (producing power at the same cost as base load power) but the question remains “can they scale to significant levels based on materials, processes and devices?”

Needs:

Some of the key needs for the large scale penetration of these technologies are not just technical, but include societal commitment.

• **To make the public aware of the challenge** – Energy and Environment have become a theme but the public does neither fully understand the global nature of the challenge nor its scale. Sustained societal adoption of these emerging technologies requires educating the public and gaining its support.

• **Energy Security** – These technologies offer individual and international energy security. In a rapidly evolving technical world, energy is a global need and it will hopefully be everyone’s right to have sufficient, sustainable, and clean energy.

• **Energy Cost** – Historically renewable energy has come at a premium price over base load cost. Some technologies (e.g. XXX) have demonstrated cost parity. However, the base load sources of coal, oil, gas and nuclear are getting more expensive which would make clean energy more attractive if it can be obtained at an affordable price.
• **Sustainability** – Technologies must be sustainable all the way from original materials development and/or extraction to end of life recycling including all the steps and processes in between.

• **CO₂/Climate Change** – Solar energy is a very clean source and offers a sustainable approach to low carbon dioxide emission if it can be scaled.

• **Scalability of Current Technology** – At present, there are significant challenges at all levels that need to be addressed in order to implement the production, deployment and use of renewable energy sources at the terawatt scale.

**Scientific and Technical Challenges**

• **Major breakthroughs in science for high penetration of renewable sources** - There are clear needs from better ways to extract and produce materials, to developing conversion systems based on green (environmentally safe) materials and processes to the ultimate recycling of the materials to be put into new devices.

• **Developing advanced materials and processes for transformational change** - Many technologies require significant improvements to be able to get to base load production costs matching the cost of present, economical technologies such as coal. Improvement of nearly every aspect of the material development and their processes needs to be achieved in order to reach a significant reduction in the ultimate cost of a kilowatt-hour, and in turn will stimulate investment in new green, lower-cost materials and device concepts for efficient capture and conversion of solar energy.

• **Penetration beyond peak load needs** – Currently it is estimated that renewable sources based on solar energy can have a large penetration of about 10-20% power within any country. A new approach is urgently needed to shift production with either a smart grid or by storing energy or directly converting solar energy into chemical fuels in order to expand the use of solar energy. This provides an opportunity for systems like CSP where storage is inherently integrated. This may also require a commitment on a national basis in developing distributed or central systems and anticipating the consequences to the technology requirements of these changes.

• **Low Cost Storage integration** – If storage is needed, there are significant technical questions related to efficient energy storage that should be addressed in order to determine a viable approach and its integration with the energy source and on the grid. Basic research needs to be done in order to address these challenges and answer some of these issues.

**Political, Economical and Social Challenges**

• **Articulate the needs for renewable sources** – A clear and easily understood case needs to be made to the public for why clean, renewable, and sustainable energy is a viable and economical option.
- **Solar is the first choice** - At present the dominating factor for societal energy investments is the lowest cost of the produced power. It is important that the clean renewable energy technologies be viewed as the first choice. The total cost to produce clean power must be reflected in the costs of all the component technologies.

- **The market is self-supporting** - It is important that while the market may initially be stimulated by incentives or tariffs ultimately it will need to be sustainable. Hence public opinion and even governmental regulations must be changed.

- **Workforce development** – Currently there is a strong need for improved technologies and, consequently training and expanding the work force to match both the research and deployment needs. The whole educational system including curricula changes should be developed to address this problem and match these needs.

- **Social and hardcore science education** – Key to good educational and informational resources is increasing the pace of research and development on an national and international level.

- **Effective public outreach** - The public worldwide needs and wants to know accurate information about energy and the environment. They also want to know about solutions and, how they can support and utilize them. This information needs to be conveyed nationally and internationally.

- **International cooperation and collaboration** – Achieving the scale desired can only be done by applying the scientific resources and capabilities internationally. A key conclusion of this panel is that these interactions need to be facilitated and enhanced.

### Technology Goals and Priorities

- **Cost-competitive with base load power** - Significant materials research needs to be done on existing systems to achieve cost reductions. New materials need to be considered and/or developed which have the potential for significant cost reduction, including device configuration and production processes.

- **Durability for economic feasibility** - Historically 25 years has been the standard for solar technologies – new economic models show that this may not be the case for other materials systems and devices. A reassessment of the degradation mechanisms and packaging needs is important for all solar technologies.

- **Replace toxic, rare and expensive materials** – Key is to have a sustainable scalable set of materials and processes.

- **Reducing energy payback time** – This requires the development of materials and processes that have a low energy overhead.
• **Scalability of processes** – This will require developing novel ways to process materials without compromising performance, and more closely achieving the small scale cell efficiency in large area modules.

• **Cradle to cradle (sustainable, recyclable)** - It is key that any technology be examined for its recyclability including all the processing steps. This should ultimately look at the positive recycling of these materials back into the next generation solar conversion devices.

**Implementation on a global scale**

*Technology*

In order to achieve clean renewable energy that is abundant worldwide and to meet the basic energy global needs it is important to develop internationally collaborative efforts to accelerate the solution of these large materials science challenges.

• **New technological breakthroughs (e.g. >30% efficiency)** - This includes the exploration of new technologies and basic understanding of materials, devices, lifetimes and processes that can lead to improved power conversion efficiency and lower cost.

• **Novel hybrid technologies (ex. Coupling PV with superconductors, storage, and thermoelectrics)** – Potentially there are considerable synergisms that can be obtained by integrating conversion, storage and transmission technologies in a direct way. This could increase conversion efficiency and reduce cost while improving deployability. Also coupling could allow for use of a much broader portion of the solar spectrum into the near-infrared.

• **Critical mass efforts meeting critical design rules** - This also necessitates an integrated effort to meet key criteria that will achieve global goals including

  – Abundant
  – Low cost
  – Environmentally friendly
  – Scalable
  – Processable
Collaboration

There is an increasing number of success stories where international teaming/collaborations can address significantly large problems. Solar energy represents just such a kind of project. Below are some examples of both approaches and examples that could be used as models for these interactions.

• ITER (International Thermonuclear Experimental Research) in France
• World Premier Institutes in Japan (ex. MANA at NIMS)
• International Transitional Research Teams
• DOE International Energy Frontier Research Centers (EFRCs)
• NSF/DMR International Materials Institutes (IMIs)
• NSF/DMR Materials World Network (MWN)
• NSF/DMR Materials Centers of Excellence for Research and Innovation
• Shared Information
• Cyber Infrastructure

Summary Key Observations for Solar Energy

• Solar energy conversion offers the potential for large scale, carbon-free power generation
• Moving to terawatt scale at grid parity needs major advancements in materials research
• Rapid transitioning from research to production requires a concerted effort and international collaboration
• Ultimately the challenges for integration of production, storage and transmission of power must be addressed.
Top Issues

• Social and Political
  – Safe nuclear power is essential for human progress in a sustainable world. Both nuclear and non-nuclear states’ governments must support a global effort.
  – Training and education is a high priority, including public outreach
  – International cooperation a priority, both in technical endeavors and in policy

• Technical
  – For today, light water technology needs are in life extension up to 80 years, especially surface effects, using today’s tools from the nano to the plant scale and relevant time scales from sub micro second to plant lifetime
  – For tomorrow, extend extreme environment (radiation, chemical, temperature) robustness of materials to Generation IV
  – For after tomorrow, fusion is an exciting future. One long lead time priority is first-wall materials.

Needs

• Policy
  – Nuclear is essential especially for baseload electricity
  – Priorities:
    • Safety, safety, safety
    • Life extension
    • Reliability
    • Inspectability
• Technology
  – Materials in Gen II and Gen II+ are in good shape for safety and reliability

Challenges

• Technical
  – Structural
  – Fuel
    o Increase T and rad resistance esp for Gen IV
  – Waste issues
    o Diffusion, heat...
  – Fuel cycle issues
    o Reprocessing that guarantees security, low volume, low toxicity

• Political, economical and social
  – Security of fuel and plants
  – Waste policy: Different countries have different needs. Need a informed decisions for the long term.
  – Public acceptance is crucial

Technology Goals and Priorities

• Light Water technology is safe and reliability and forms the core technology globally
  – Already forms a high fraction of base load in several countries
  – Sustainability is mathematically limited

• Gen III is in hand but can be improved. (It is safe ONLY by comparison to other technologies such as coal AND it potentially exposes the public.)

• Gen IV, Technologies after light water include: fast reactors, Th, possibly Super Critical...
• Fusion needed for far future

• Multiscale modeling in a wide variety of materials science issues including
  – Alloy design
  – Stress corrosion cracking
  – Manufacturing process (Thermo mechanical, ...)

• Irradiation
  – Facilities for research samples
  – Modeling, validated
  – Neutrons and other particles as available and needed

• Infrastructural needs

• Rad waste and recycling needs

• More effort needed in FAST REACTOR materials issues
  – Radiation tolerance up to 200 dpa
  – Chemical reactivity issues
  – Compatibility, dissolution, transport with liquid Na
  – Transport of impurities in coolant
  – New fuels that utilize minor actinides

• Safety cultural change needed; Otherwise a single accident will end the endeavor!
  – Superb training needed
  – Rigor (following the Rickover paradigm)
    • Engineers must have total mastery of plants
    • Vendor regulation required

• International development and agreement needed
  – Standardization needed to un-complicate the market

• Global database sharing AND UNDERSTANDING
  – On materials, modeling, and safety issues
Implementation at Global Level

• Opportunities: New Technologies
  – Gen IV: In addition to Fast Reactor technology, may also consider super critical, gas cooled (but not fast) HIGH T, Th options as studies recommend

• Approaches: Together we can get there
  – Public acceptance might be helped through social science techniques—varies country to country
  – Education is key
    • Public awareness
    • Technical education for sustainable design, operations, research to ensure future
  – Knowledge management
  – Cooperation
  – Public exposure studies, shared
  – Risk is perceived differently across the world
  – U supply
  – Treatment of spent fuel, with eye to counter proliferation
  – Decommissioning of old plants
  – Cost reduction, will it remain competitive? Gen III AND IV promise competitive pricing
  – Can nuclear be considered a bridge technology that gets phase out?
Fuel cells is the cleanest and most efficient way of converting chemical energy directly into electrical energy without combustion. Owing to its high energy density, hydrogen is an ideal energy carrier for storage and transport in an economy based on renewable energy. CO2 capture is another important challenge for a sustainable energy future. Two types of fuel cells are currently in common use: PEMFC (proton exchange membrane fuel cell) and SOFC (solid oxide fuel cell).

1. Needs
   a. Policy
      • Foreseeing the increase of the energy need for global economic development, and considering energy security, increasing price of fossil fuels, the common consensus of reducing the GHG effect, and advancing a clean way of converting energy needs to be established, and fuel cells should be one of the choices. Hydrogen is an attractive energy carrier for mobile applications and energy storage provided that further developments occur. Emphasis should be given to the development of fuel cells.
      • Hydrogen is an ideal agent for stabilizing the intermittent aspects of some renewable energy sources.
      • Industry, academia, and national labs should work with government support to accelerate the focused development as well as the introduction of fuel cells to the market place.
      • Significant progress is being made and continued financial support is warranted.
      • Tax incentives should for deployment of prototype fuel cell systems.
      • Government subsidies and sites for early market penetration of fuel cell systems in meaningful quantities.
      • Facilitation of global collaboration to address major technical barriers to commercialization.

   b. Technology
      • SOFC’s for high efficiency and low pollution power generation from a variety of fuels, such as gaseous and liquid hydrocarbons, coal and biofuels, etc. and PEMFC’s for high efficiency and no pollution power generation from renewably produced hydrogen.
      • Hydrogen is an excellent way to store excess energy from the grid.
• For applications in residential, portable military, transportation auxiliary power unit and large distributed power generation.
• For applications in vehicle propulsion, mobile power unit, and distributed power generation.
• SOFC’s provide a unique technology for CCS.

2. Challenges
a. Technical challenges

HYDROGEN PRODUCTION

• Achieve efficient separation and purification of hydrogen for many applications.
• Improve catalysts for the water gas shift reaction (present dominant method).
• Improve efficiency for hydrogen production from coal and hydrocarbons.
• Improve the quality and stability of the materials used in water splitting.
• Decrease the cost of hydrogen production.

Hydrogen storage and delivery

• Increase the storage density of hydrogen for mobile applications.
• Increase the efficiency of hydrogen storage and release.
• Alleviate the safety concerns with hydrogen storage, handling, and delivery.
• Construct an infrastructure for hydrogen delivery.
• Establish international codes and standards for hydrogen storage and delivery.

FUEL CELLS

• Increase performance and performance stability.
• Decrease cost.
• Increase lifetime.
• Establish international codes and standards for fuel cells.

PEMFC

• Develop catalysts with low or no noble metal content.
• Develop membranes capable of operating at higher temperatures.
• Develop cells with higher tolerance to impurities such as CO in the fuel.
• Improve water management in the fuel cell.
SOFC

- Elucidate performance degradation mechanisms.
- Develop high performance and stable cathode materials.
- Develop redox tolerant and sulfur resistant anode materials.
- Develop long lifetime sealant materials.
- Develop metallic interconnects with high oxidation resistance and high electrical conductivity.
- Develop low cost fabrication techniques for cells.
- Develop life cycle analysis and sustainable disposal.

b. Political, economic and social challenges

- Maintain political support for development of hydrogen and fuel cell technology.
- Improve public perceptions and acceptance.
- Lower the cost.
- Provide government incentives for industry to take greater risks in developing these technologies.
- Address public concerns regarding safety.
- Increase public awareness of the benefits of these technologies.

3. Technology goals and priorities

HYDROGEN PRODUCTION

- Use nuclear reactors to provide excess generation at nighttime to perform electrolysis at lower cost.
- Achieve higher efficiency and lower cost for solar, photovoltaic, photoelectrochemical, and photocatalytic hydrogen production.

HYDROGEN STORAGE

- $2,000/tank for automobile applications.
- 75g Hydrogen/kg and 70g Hydrogen/L (at system level).
- Below 3 min refueling time.
PEFC

- Cost: less than $35/kW for vehicle applications and less $1000/kW for stationary power generation.
- Lifetime: 3,000 h for vehicle applications and 40,000 h for stationary power generation.
- Performance degradation: less than 0.1%/1000 h
- Thermal cyclicability: 5 per year for stationary and large number for vehicle.

SOFC

- Cost: less than $1000/kW for stationary power generation
- Lifetime: 40,000 h for stationary power generation
- Performance degradation: less than 0.1%/1000 h
- Thermal cyclicability: 5 per years

4. Implementation at global level

- Opportunities
  - Government is offering tax incentives to create an attractive environment for the development of fuel cell and hydrogen technology.
  - Depletion of fossil fuels and global warming provide the motivation for the use of the fuel cells and hydrogen technology.
  - To produce hydrogen in large quantities for the conversion of CO$_2$ into liquid fuels. For implementation of this approach, nuclear power obtained more cheaply at night-time could be used as a energy source.

- Approaches
  - Government offer tax incentives to create an attractive environment for the development of fuel cell and hydrogen technology.
  - International field testing of prototype systems. As an example, over 3300 units of 1kW residential fuel cells have been installed and their commercialization has started in Japan.
  - bi-lateral and multi-lateral collaboration for pre-commercial R&D.
  - International field testing of prototype systems.
Energy storage is a key technology for electric vehicle transportation, integration of renewable energy and load leveling and on the grid.

Li-ion Batteries (LiB)

Lithium batteries represent an efficient solution for CO$_2$ abatement in the transportation sector. They are in demand by consumers, city planners and governments preparing for Copenhagen meeting. If fuel cells (H$_2$, MeOH) succeed over the next decade or beyond the demand for LIB will not diminish, as cars will still be hybrid electric vehicles (HEV), or electric vehicles (EV) with range extenders. LIBs are predicted to enter the industrial phase for electric vehicles and hybrid electric vehicles in 2010, with emphasis on small urban cars. Plug-in HEVs will depend on improvements on energy density, especially for the New World market where daily distances are larger. The positive electrode materials based on transition (Fe) metal phosphate solve the problems of safety and lifetime for this part of the battery. This material will experience a growing market and is still the object of improvement, especially in terms of packing density in the electrode, grain size distribution and electronic wiring. To ensure full safety of LIBs, the next frontiers are improvement in the electrolyte (conductivity, temperature of operation, flammability…) and possible replacement of the graphite electrode by silicon (the use of tin introduced by Sony is unsustainable), and later copper by aluminium, which implies negative electrode materials with high capacity in the ≈ 500 mV operating range.

In the future, LIBs are expected to reach ≥ 200 Wh/kg including BMS, which will double the range of EVs. Busses as full EVs or HEVs will be in demand in the future for suburban networks connecting to big cities with tramways or underground metro systems.

Despite remarkable progress made over 30 years, LIBs still represent a formidable materials challenge. Information should be exchanged freely and cross-fertilisation among solid-state inorganic scientists, organic and polymer chemists is needed for improvements in electrolytes, corrosion additives and packaging. Organic and polymer chemists are under-represented in the LIB community. It is suggested to broaden the scope of conferences on the subject by inviting scientists from fields that have been extremely successful in implementing new technologies on organic materials, such as OLEDs. An important question is the access to key patents: governments should consider agreements that limit exclusivities when a new materials/processes appears in order to accelerate implementation. Reliable surveys of primary element resources should be made at the global level, rather than relying on reports from private sources that are made on demand and may encourage speculation.
Sodium Sulfur Battery (Na/S)

Great achievements have been made in developing Na/S battery for large scale energy storage applications, covering uses such as load levelling, emergency power supply and uninterruptible power supply. The potential markets include industrial and commercial companies and wind and solar power generating systems. Up to now, more than 140 NaS energy storage stations are in running in the world with the largest power reaching 34MW. Sodium sulfur batteries use sodium and sulfur as the anode and cathode respectively, and beta-\(\text{Al}_2\text{O}_3\) ceramic tubes as both the electrolyte and the separator simultaneously. Other battery components include the current collector, insulator, electrode filler, sealing materials and cell container. Among all the components, beta-\(\text{Al}_2\text{O}_3\) ceramic tubes are the most difficult and expensive. The production capability of NaS battery is lower than 150MW/y at this time and the cost of the battery is high, reaching about $250/kWh. Reducing the production cost of the ceramic electrolyte tubes and of the battery, improving the reliability and expanding the research and development effort will be main tasks in the future. The production ability of NaS battery in China is expected to be over 100MW in 2015, targeting the cost of 1500$/kW with lifetime longer than 15 years.

Redox Flow Battery:

Redox Flow Batteries (RFB) electrochemically store/release electricity by the valence change of the active species in the electrolytes that circulate through the anode and the cathode, separated by an ion exchange membrane. The available power is determined by the number of cells in the stack. The available capacity is determined by the volume and the concentration of electrolyte in the charged state. Though many successful demonstrations have been carried out, there are still significant challenges for commercialization of the vanadium redox battery (VRB), including low concentration of the electrolyte, imbalance of the electrolyte, low current density and high cost. All these challenges arise from the materials used. Materials with high performance, low cost and easy mass-production are needed, including (i) electrolytes of high stability, high concentration and low cost, (ii) membranes of high conductivity, stability, low active ion permeation and low cost, and (iii) bipolar plates of high electric conductivity, high stability and low cost. In addition, system integration and scale-up to mega-watt level energy storage systems is a challenge. Technology goals and priorities of RFB are low cost, high stability and durability.
Needs (Policy/ Technology)

1. Public opinion
   - LCA for bioenergy
   - educated people, public, many kind biomass
   - awareness, participation
   - More recycling desired

2. Energy security
   - sustainable, clean, renewable, affordable
   - Benefits all regions for energy independence
   - liquid fuel for transport or such as car

3. Energy cost
   - Competitive with fossil sources
   - Include environmental cost/compatibility
   - Energy balance/net energy

4. Climate change and environment Policy makers
   - Carbon credit
   - “Kyoto protocol” implementation
   - Energy reduction credits/substitution credits
Challenges

- Technical challenges
  1. High cost for cellulose materials treatment: cheap Enzymes
  2. Complete and highest value biomass utilization
  3. Year round raw material supply - logistics
  4. Clean “Green” manufacturing and agricultural production technologies
  5. Development of efficient recycling processes and technologies
  6. Evaluate systems for bioenergy so they can be compared accurately – Standards are needed
  7. Process at appropriate scale so they can be distributed

- Political, economical and social challenges
  1. Balance between food, fuel and other land uses economic biomass crops should not compromise food supply
  2. Development of government policies and incentives with appropriate implementation strategies
  3. Profitable and sustainable investments competitive with fossil sources
  4. Culture change to value recycled material over new (for example) and energy efficiency improvements etc.
  5. Converting away from growth driven models (quantity) to include an emphasis on quality

Technology goals and priorities

- Commercialize production of bioenergy from cellulosic raw material
- LCA complete and communicated
- Set bioenergy targets for % of total
- Complete renovation and renewal of energy and transportation infrastructure - Including adaptation of automobile, jet engines, power stations to renewable sources
- Developing efficient recycling technologies
Implementation at global level

• Opportunities

1. Investigating collaboration in having global standards and targets
2. Collaboration in R&D
3. Transfer and share best technologies – availability to all countries
4. Multi-nation and multi-discipline implementation of pilot and scale up facilities
5. Make new technology available to the portion of the world population that is underserved for food and energy

• Approaches

New technology:

1. Enzymatic treatment of cellulose to sugar
2. High efficiency for fermentation: C5 and C6 sugar will be used
3. Green processes including recycling
4. Biomass production systems research and integration
5. International collaboration on research, markets, and standards

Summary

• Bioenergy is a renewable and sustainable energy.
• We have large amount of biomass for bioenergy production and can produce more.
• Balance between food, fuel and other uses needs regular transparent discussions.
• Some technical problems need to be solved before large applications
• Education about LCA, sustainable benefits to all regions and cost effective energy yields is needed to improve international cooperation and create widespread availability of carbon credits and support from society.
Technical Report F

Alternative Energy Sources & Transmission

*Chairs: Chen Lidong and Hanns-Ulrich Habermeier*

**Needs (Policy/Technology)**

- Public opinion is aware of the challenge
  
  Partially (ask aunt Mary – buy a sweater)

- Energy Security
  
  more safety rather than security concerns

- Energy Cost
  
  cheap environmentally friendly energy is a must

- Climate Change
  
  increasing awareness

- Policy Makers are ready for action
  
  ?????

- The industry has technologies available
  
  partially

**Challenges**

- Technical challenges
  
  CAPABILITY AND EFFICIENCY
- Political, economical and social challenges

**MATERIALS ARE THE BASIS**

Generate the political will to solve the energy and global warming problem

Taken from Li Wei
Technology goals and priorities

Solve energy problem reduce global warming by implementation of diversity or renewable energy and energy efficiency

WHERE ARE THE MATERIALS NEEDED??

Implementation at global level

Necessary funds required to implement international cooperation for

- Basic research to understand existing materials and phenomena and to tailor artificial materials and discover new phenomena
- Cooperation between need driven and curiosity driven research activities
- Implementation of integrated innovation cycles
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Report of the Second World Materials Summit

Executive Summary

The Second World Materials Summit was held on 12 to 15 October, in Suzhou, Jiangsu Province, China on the topic of “Advanced Energy Materials and Sustainable Society Development.” It was hosted by the Chinese Materials Research Society (C-MRS) and was attended by more than one hundred distinguished scientists, government officials, and business leaders from all over the world. These delegates came together to evaluate the current status of research and its application to advanced energy materials. In particular there was much discussion of the role of new materials in the development of renewable energy sources such as direct solar, wind, and biofuels. Also discussed were nuclear sources (fission and fusion) and clean coal technology. The future paths of these technologies and the level of effort required for success was also discussed. A declaration was developed to be presented at the next United Nations Climate Change Conference in Copenhagen in December (7th to 18th).

The conference opened with a cultural visit to a Suzhou garden in the morning and a technical visit to the Suzhou Industrial Park in the afternoon. There the delegates saw a model of the industrial park.
The industrial park is receiving a great deal of investment from the Chinese government resulting in great technical progress but also great architectural progress as can be seen from the garden shown here.
There were thirty high quality papers presented in the main session by authors from the United States, Europe, Japan, Taiwan, Australia, India, and China. The papers ranged in topics from technical to policy making and there was a great deal of agreement among the authors that carbon in the atmosphere is a major problem for the future on mankind.

A summary of each of the major presentations is given below.

New Materials in the Advanced Powertrains – the Future of Volkswagen’s Electric Vehicles
Jörg Huslage, Research Group Electrical Drives and Fuel Cells of Volkswagen Wolfsburg, Germany.

Volkswagen has concluded that the best solution to the CO₂ emission crisis will be the use of electric vehicles. Renewables have become important with hydrogen being the energy carrier. New engines will be downsized and efficient with electric-drive being the preferred technology.

**Volkswagen’s Fuel- and Powertrain Strategy**

Cost is the most critical challenge and lithium ion batteries may be the answer. What is needed from an energy storage system for vehicles is high-energy and high-power but not at the same time. High energy cells with high specific energy and low specific power require thick electrodes. These are for “Marathon Runner” applications like the electric vehicle. High power cells with high specific power and low specific energy require thin and more porous electrodes. The applications for these cells are for “100 meter Sprinter” hybrid vehicles.

Lithium cells are under development.
There are several concepts for the powertrain.

**Electrifying the powertrain**

**Structures and features of selected concepts**

- **Full hybrid**
  - Parallel hybrid
  - EM output ~ 15 kW
  - Direct coupling via 6...7-speed gearbox
  - Concept for consumption reduction

- **Booster**
  - Plug-in hybrid I
  - Parallel hybrid drive with performance improved electric unit
  - Direct coupling via 4...5-speed gearbox
  - Concept for small electric ranges (approx. 5...30 km)

- **twinDRIVE**
  - Plug-in hybrid II
  - Parallel / serial hybrid drive systems as inline concept
  - Direct coupling via single speed gearbox
  - Concept for medium electric ranges (approx. 30...80 km)

- **Range extender**
  - ICE or FC
  - Serial hybrid drive system
  - Direct coupling omitted
  - Concept for high electric ranges (approx. 80...120 km)
Questions included the use of hydrogen in internal combustion engines rather than fuel cells, Huslage said that such uses are very inefficient. He also noted that in an electric car with a range of 100 km people would only drive 70 km for fear of running out of power. He mentioned that Daimler already sells cars based on the lithium ion battery technology.

Katsuhiko Hirose of the Toyota Motor Corporation of Tokyo, Japan

Hirose San started by saying that the high price of oil can seriously affect the trade balance of a nation. To combat this we need to use more public transport and provide an alternative fuel or energy source for our vehicles. He went on to say that Tokyo, London, and Paris are very exceptional cities in the world because billions have been spent in these cities on public transportation. The most promising candidate to reduce CO₂ emission and to keep the high quality of mobility that we have all come to expect is hydrogen. Instead of choosing between batteries or hydrogen, Hirose advocates batteries and hydrogen.

The main challenge for fuel cell vehicles is the catalyst for the fuel cell stack. It needs to have low or no platinum content. The durability of the catalyst and membrane is an issue together with the development of a high-temperature electric membrane. Hydrogen storage is also an issue requiring a low cost tensile fiber for the storage containers together with a high volumetric hydrogen storage material.
The issues we face are all interconnected: population increase, rich and poor, unstable world, lack of energy, environmental pollution, and climate change. Materials developments will help us to cut these connections. “The end of the stone age was not due to the lack of stone” and new material will lead us to technical innovation and change society to a sustainable one. The new “axe” material is hydrogen and electricity.
Current fossil energy sources, current energy production methods, and current technologies cannot meet the energy challenges we now face. We need transformational discoveries and disruptive technologies rooted in the ability to direct and control matter down to the molecular, atomic, and quantum levels.

Five areas where science and imagination can impact energy security are: solar energy utilization, electrical energy storage, bioenergy, nuclear energy (fission and fusion), and hydrogen production, storage, and use.

For solar energy the technology requires: photovoltaics exceeding thermodynamic efficiency limits (e.g., multi exciton generation from a single photon), easily manufactured, low cost polymer and nanoparticle photovoltaic structures, efficient photoelectrolysis, defect-tolerant and self-repairing systems, bio-inspired molecular assemblies systems, and new experimental and theoretical tools. To take advantage of intermittent energy generators like wind and solar, efficient energy storage is required. Batteries and ultracapacitors will benefit from advances in nanomaterials. Nanoscale science will also benefit biofuel production by aiding the design of catalysts for biofuel production.
Nuclear energy presently provides 20% of the USA nation’s electricity and could provide more. The issues are the disposal of spent fuel and the threat of nuclear proliferation. By closing the fuel cycle the spent fuel can be burned in fission reactors. Cracks in the “first wall” of containment of the nuclear process are a problem but experiments with copper-niobium are looking promising. Fusion holds great promise and China is a major partner with the US in building a fusion reactor.
The hydrogen economy is a compelling vision that provides ample and sustainable energy, flexible interchange with existing energy technologies, and a diversity of end uses to provide electricity through fuel cells. Basic research is needed in hydrogen production (catalysts, photocatalysis, bio-production, solar and nuclear), hydrogen storage (hydrides, nanoscale materials, theory), and fuel cells (electrocatalysts and membranes, low temperature fuel cells, and solid oxide fuel cells).
The speaker started by showing that the primary source of energy in China was from coal (68.7%), followed by oil (19.5%) and hydro and nuclear (8.0%). He said that China was the largest country producing at least 90% of its energy internally and that the emphasis was on lean energy production.

Clean coal was a major effort with a coal-based solid oxide fuel cell using an integrated gasification combined cycle (IGCC) and an integrated gasification fuel cell system (IGFC). There was work going on to reduce the temperature of operation of the fuel cell from 1000°C to 600°C using Fe-CeO$_2$–Cu catalysts to produce hydrogen.

By 2020 4% of China’s electricity will be produced by nuclear power (30 new nuclear power stations) and 16% by 2030 (160GW). He showed an International (Thermonuclear) Experimental reactor (ITER) where functionally graded materials will be used as a first wall.

China has the most hydroelectric capacity of any country in the world (300MKW by 2020) and the Three Gorges Dam plant produces electricity equivalent to 50M tons of coal reducing CO$_2$ pollution by 100M tons.
Electricity loss has been reduced by the introduction of superconducting cables which transport more than 500M KWh of power and work is progressing on improving the quantum efficiency of white LEDs to 60%. He also described work on improving the insulating properties of window glass for buildings.

Wind power is also important and by 2020 3% (30MKw) of the nation’s power will be produced by wind and these numbers will also be achieved by solar power. Solar furnace has already been used to produce silicon single crystals.

Energy storage has also been tackled by the development of Na/S cells and Li-ion batteries particularly for transportation applications.
Energy is one of the biggest challenges to be faced in the next decades in order to cope with world population needs, depletion of traditional resources, and obligations to mitigate emissions of greenhouse gases.

The strong asset of nuclear energy is to ensure on a long term a substantial fraction of the base load of electricity production and thus to efficiently adapt future intermittent renewable energy supplies such as solar or wind. The matter is that of a choice between nuclear or renewables, the matter is that nuclear and renewables have to go together.

However safety requirements, reduction of proliferation risks, waste management, highly reliable and competitive cost industrial operation, as well as public acceptance appeal for important and long term efforts in science and technology.

The talk reviews some of the basic science issues which are at stake: major advances in the understanding and prediction of materials property under severe conditions, advanced chemistry for mastering the fuel cycle, nuclear data, and large scale computational simulations.

There is a need for substantial R&D to ensure a nuclear future. For extending the life of reactors there needs to be better (new) materials to sustain higher irradiation, chemical corrosion, mechanical stress, and higher temperatures. Fast Breeder Reactors need core studies for a better void coefficient and for a better breeding factor without blankets. A transition from oxides to carbides (higher density and thermal conductivity) or metals. Work must also be done on the recycling of minor actinides (MA) by the homogeneous incorporation of MA in fuel and heterogeneous recycling. Waste management must also be considered by studying the ageing of glasses and the transport of radionuclides in clay.

There are strong demands for new materials both for cladding and structure as well as fuel. These include materials able to sustain intense irradiation (fast neutrons), high temperature, high constraints and corrosion, and high burn-up. There are ageing issues requiring new grades of steel (oxide dispersion strengthened steel (ODS) for cladding resisting swelling and high temperature) and ceramics and...
composites (SiC-SiC...) for resisting very high temperature. Liquid metal technologies also need to be studied.

A massively multiscale problem is that of the damage of materials under irradiation. Defects created by irradiation are interstitials and vacancies and these form migration and extended clusters which in turn effect the mechanical properties, cause performance degradation and failures. Neither experiment nor theory has yet captured the complexity in a single framework. We must go beyond observation and modeling to control the evolution of defect structures and interrupt their development before performance degradation sets in.

The Wigner effect is the formation of metastable defect structures and the energy stored by defects can lead to a catastrophic release of energy (remember the Windscale fire due to a graphite moderator at 200 to 250°C).

Experimental needs include in-situ measurements of neutron irradiation with atomic or nano-scale resolution for initial damage processes. Also required are coarse-grained experiments to capture migration, formation of clusters, and degradation of main properties like ductility and toughness. There needs also to be synthesis of nanostructured materials for trapping defects at interfaces before they cluster. This will provide defect-tolerant materials which are self healing.
Renewable Energy met 13% of global primary energy demand in 2006 and the IEA projects this renewable energy share to remain relatively constant through 2030 under “business as usual” scenarios. However, there will be significant changes in the renewable energy mix as the use of wind, solar, geothermal, and biofuels for transportation continue to see rapid increases in use. Traditional use of biomass for cooking and heating, which are often not sustainable, are projected to decline. The bottom line is that we will need new energy sources and approaches in order to provide the energy required to power not just our countries, but the world.
Today’s US energy system depends on foreign sources, prices are volatile, it is unreliable, 60% of the energy is wasted, and it produces 25% of the world’s carbon emissions. A sustainable system needs to be carbon neutral, efficient, with diverse supply options, have minimal impact on resources, create jobs, and be secure.

For more efficient use of energy, energy buildings must be designed and built. They will have photovoltaic arrays on the roof, compressorless cooling, electrochromic windows, polymer solar water heaters, and computerized control of the house.

For a renewable electricity supply, wind technology is a major resource, exceeding the total electrical demand in the US. Components of the technology are offshore wind, advanced blade designs, tall towers, giant turbines, and effective wind forecasting. Modeling is important since turbulence can affect the efficiency of wind farms as can be seen in the following figure.
Nanotechnology will play a big part in the reliability of wind and ocean systems.

Solar heat and electricity in the form of solar thermal, photovoltaics, and concentrating solar power (CSP) will have applications to transportation, residential and commercial buildings, and industry. Projects being investigated in photovoltaic conversion include thin films on low cost substrates, organic photovoltaics, advanced concepts for improved performance, crystalline silicon efficiency improvements, concentrating photovoltaics, dye sensitized cells, and integrated photovoltaics.

Biofuel development includes the action of fungal cellulases and “beyond ethanol” considerations like higher energy density, better temperature and cold start ability, algae use, and infrastructure compatibility.

Sustainable transportation includes energy storage and advanced power electronics while energy storage includes hydrogen storage, novel electrolytes for batteries and ultracapacitors. Lithium ion batteries are the technology of choice at the moment but the author is an advocate of the hydrogen economy.

The opportunity for making renewable energy transformational change is now before us as a solution to a global crisis. We must seize the moment.
European Energy Policy and its application in Poland
Prof. Krzysztof J.Kurzydlowski, Warsaw University of Technology

Professor Kurzydlowski started by stating that the European Union (EU) is at the forefront of tackling climate change and is implementing three initiatives. These are improving energy efficiency, decoupling economic growth for energy consumption, and saving energy (20% could be saved by 2020). In addition the EU is emphasizing renewable energy sources, carbon capture, and clean fossil fuel technologies. Countries can choose to keep carbon-based sources in their energy mix but the aim is to have near-zero emissions from coal after 2020. Coal accounts for about 30% (over 90% in Poland) of electricity generation in the EU.

The short term Strategic Energy Technology (SET) Plan is for new generation biofuels, the capture, transport and storage of carbon, and improving energy efficiency in construction, transport and industry. The longer term plan is for low carbon technologies, renewable energies, energy storage, fission, fusion and trans-European energy networks. There are also new European industrial initiatives to capture, transport and store CO$_2$ with a provision for international cooperation.

Such international cooperation in low carbon technologies will require public interest research and long-term exploratory research and the networking of research centres, large-scale demonstration projects and increased use of the mechanisms of the Kyoto Protocol. A total of 2.35 billion Euros has been set aside for energy research for 2007 to 2013 for hydrogen and fuel cells, renewable electricity generation, fuel production, and heating and cooling. CO$_2$ capture and storage (zero emission), clean coal, smart energy networks, and energy efficiency and savings are also included.

The energy policy of Poland is to pursue the goals set by the EU, to remain realistic about changing the energy mix overnight, and to effectively use the fossil fuel (coal) in Poland. This includes using coal-originated methane and the production of coal-based liquid fuels and coal-based fuel cells. Poland also wants to explore fission-coal synergy and use hydrogen as an energy carrier, together with the development of geo-thermal energy, bio-gas and solar.

Coal will remain important in power generation in the coming years and the main objective for the World Energy Policy is to efficiently use the fossil sources of energy (coal deposits). This requires new clean coal technologies, based on new functional materials.

The challenge is global; the response should be global as well.
Solar photovoltaics: What does the future hold?
Martin A. Green, University of New South Wales, Sydney

The first generation of silicon wafer-based solar cells cost $280/square meter with an efficiency of 14% (140W/sq m) and a manufacturing cost of $2 per watt. The upper bound on efficiency is 30%. There has been more silicon used for solar cells than for microelectronics since about 2006, with the transition causing an escalation in costs, so the thrust has been to make the silicon thinner by using thin films and to simplify the silicon purification.

The second generation of cells are based on thin-films of photoactive material and include amorphous, microcrystalline, or polycrystalline silicon or polycrystalline chalcogenide (CIS, CIGS (Cu(In,Ga)(Se,S),2 or CdTe) or dye sensitized cells or organics. These have the potential to bring the cost down to $1/W.

Third generation devices target thermodynamic limits on solar conversion efficiencies, having a theoretical efficiency limit of 74% not 31% and are based on a range of approaches including tandem cells.
Besides using thin films, third generation cells target use of abundant materials (tellurium for instance is as almost as rare as gold), that are non-toxic, and be durable and stable. A tandem cell made of chalcogenides is complex and has several drawbacks. It contains toxic cadmium and selenium, rare tellurium, indium and gallium, is moisture sensitive, and cadmium telluride cells are difficult to make transparent to infrared, thereby losing that part of the spectrum.

Micromorph cells based on silicon in hydrogenated amorphous and microcrystalline material are the first real third generation cells but are still relatively low in efficiency and require slow deposition.

Other groups are looking at organic cells with many layers. An efficiency of 6.5% has been claimed.

Quantum dots have been used in silicon dioxide based devices to control the bandgap and tandem cells have been built.
Hot carrier cells have been investigated where the photogenerated carriers are removed before they have time to relax. They have the potential of reaching 68% efficiency theoretically.

Impurity band cells are another possibility while materials like lead selenide can produce multi exciton responses and have the potential of reaching 44% efficiencies.

To reach their full potential, photovoltaic cells need high efficiency and low cost. Tandem thin-film cell stacks appear to be the most promising. Nanomaterials can add the flexibility for advanced concepts and a healthy industry is healthy accelerates commercialisation of new technology.
Advanced Thin Film Materials for Solar Cells: Challenges and Limitations
Daniel Lincot, Institute for R&D on Photovoltaic Energy (IRDEP-joint Lab CNRS/EDF/chimie ParisTech), Chatou, France and Abdelilah Slaoui, Iness (CNRS/UdS), Strasbourg, France

Professor Lincot started with a review of the existing photovoltaic technologies.

87.5% of the world’s photovoltaic production is based on wafer-based crystalline silicon solar cells. The remaining 12.5% are based on thin films, 6.4% are cadmium telluride based, 5.1% are amorphous silicon, and 1% are copper indium diselenide (CIS) based. The emergence of CdTe thin film solar cells is spectacular, predominantly by only one company, First Solar, which has produced 500MW of modules in 2008, and is expected to become the premier PV company in the world in 2009. Production costs are
already below $1 per watt, making this technology the cheapest one. Record efficiencies are 16.5% for cells and about 11% for modules.

Amorphous silicon thin films have evolved into multijunction structures involving silicon-germanium alloys with bandgaps from 1 to 1.7eV and record efficiencies of 13% (3 junctions). Flexible layers of these materials are now a commercial product with cell efficiencies of 8.5%, module efficiencies of 6.7% and a projected cost per watt of $1.02 in 2012 with a possible total power of 1GW. Combined amorphous-microcrystalline solar cells (polymorph cells) are considered as new challengers in the field.

Inorganic thin film solar cells and Si multijunction photocells can be made into very large modules

The challenges for silicon-based thin film solar cells are that although 13% efficiency has already been achieved with multijunction solar cells and 20% possible is considered as possible in mid term (2020), higher values will be difficult.

There is no problem of materials availability for silicon (there is a question mark for Ge) which are optimal conditions for obtaining terawatts in the future. The cost reduction depends on process optimization (growth rate).

Cu(In,Ga)(Se,S)₂ (CIGS) solar cell technology is emerging and should progress like the CdTe technology within the next years. Cells have reached an impressive record efficiency of 20% in 2008, while modules present efficiencies from 11 to 14%. As a function of time the basic structure of the device has been optimized step by step.
Indium availability is a challenge so that indium content will need to be reduced by the year 2020 to no more that 20 tonnes per gigawatt from the 80 tonnes per gigawatt presently. Thinning the layers will need to be aided by light trapping, yet to be developed. The production can rise up to 20 GW per year in 2020.

Challenges for CIGS-based thin film solar cells are that although 20% has already been achieved with a single Junction, 25% should be possible in the future. The optimization of wide bandgap solar cells should give more than 30% in multijunction configuration. While indium availability is not a problem at the multi- GW level, for the TW level there will be a need for its substitution.

Cadmium telluride solar cells are being produced on multi megawatt (1.15 GW in 2010) production lines (First Solar) at costs of $0.87/W and are expected to go to $0.65/W in 2010.

CdTe based thin film solar cells are likely to be the winner for PV electricity cost reduction. 16.5% efficiency has already achieved with a single Junction and 20% is possible in the future. Coupling with a low bandgap material will give more than 30% in multijunction configuration. Te availability is no
problem at the multi GW level but like indium will need to be substituted at the TW level. Cadmium toxicity is controlled with minimum risk by specific regulations for deployment and recycling procedures.

It appears that thin film technologies will become increasingly important in the future, and progresses are very fast. A thin film technology company is number one for the first time. Moreover, it uses a chalcogenide material showing that non-silicon thin film materials can play a major role in this development. CdTe and CIGS are opening new avenues in this direction and will stimulate intensive research, together with an expected concomitant development of new generations of thin film silicon solar cells.

**Photovoltaic Progress in Taiwan**
Rongchang Liang and Chorng-Jye Huang, Del Solar Co., Ltd., Chinese TaiBei.
In Taiwan fossil fuels account for 91% of the total energy supply with crude oil being the major portion (53%). 99% of the total energy supply is imported. Coal is 30.3%, gas is 8.6%, nuclear is 8.2% and renewables are 0.4%. This is a real problem.

The annual growth if installed electricity capacity was 4% which cannot keep up with the demand (6%) increase.
The energy policy of the Taiwan Government is shown below.

The main features are to promote renewable (15% by 2025) and a green energy industry.
Photovoltaic promotion and industrial development are a key part of the government plan. The target for solar photovoltaics (PV) requires a growth rate of 100% per year through 2010 and 30% per year after that until 2025.

The main thrust of PV will be in amorphous silicon thin films, in CuInGaSe₂ (CIGS) thin films and crystalline silicon. Taiwan companies are working together to build the new standards for the end user customers.
PV Industry and Technology in China
Dinghuan Shi, Counsellor of State Council, President, China Society for Renewable Energy and Yafang Han General Secretary, C-MRS Professor Han started by outlining the problems faced by China’s energy sector.

The demand for energy will grow continuously and rapidly. Energy demand has increased by one billion tons of coal between 2001 and 2006 and the energy demand related to automobiles and housing is a new phenomenon. This has lead to environmental problems emerging in the form of coal smoke and greenhouse gases. Energy security and the protection of the environment present competing pressures.

Presently China relies too much on fossil fuels.

Second World Materials Summit

China’s Present Status of Electric Power Structure
1. E.P. structure is imbalance
2. heavy reliance on fossil fuels

Thermal power accounts of 81% for China’s power production in 2008 was far beyond the average global level. Pushing renewable energy development became a general trend for China.

12-15 Oct. 2009, Suzhou, China
China’s basic strategy in developing renewable energy consists of government support (compulsory market regulation and economic incentive policy), legal guarantees (use overseas experience, compel power companies to purvey or purchase renewable energy power through legislative provisions), introducing competition, technological progress, and international cooperation.

By 2010, China will aim to raise the share of renewable energy in total primary energy consumption to 10%. By 2020, it will aim to raise this share to 15%. In 2008 renewable energy was being generated by four major methods that had developed rapidly.

**China's Renewable Energy Development In 2008**

- **Wind Energy**: By the end of 2008, China’s total number of wind farm projects reached 239, with a total installed capacity of 12.17GW. By June 2009, large-scale grid-connected total wind power capacity will reach 11.81GW.

- **PV**: In 2008, China’s PV cell production reached a record 2.65GW, accounting for 26% of the world’s total, first in the world.

- **Biomass**: National biomass installed capacity reached 3.15GW, with an annual output of 1.85 million tons of bio-liquid fuels. More than 1600 large scale biogas utilization projects and 30 million biogas digesters in rural areas have been completed.

- **Hydro**: By the end of 2008, China’s total hydropower installed capacity reached 172GW, accounting for 21.6% of the country’s total electricity generating capacity.

China has already completed a number of photovoltaic renewable energy projects.
There are still a number of problems facing manufacturing in the photovoltaic industry. The renewable energy laws and implementation remain poor due mainly to opaque approval procedures. Grid-connected PV power generation requires a 50K-60K RMB initial investment and is priced at 3-5 RMB/kWh, ten times higher than conventional thermally generated power. Innovation and core technologies need to be improved and product brands need to be established. Standards are still...
lacking for issues relating to safety and compensation and training for technical personnel may be further enhanced.

China has great potential for photovoltaic generation. Prior to 2010, cumulative installed capacity was 50MW; by 2020, China will have an installed capacity of 700MW. Of China’s approximately 5 billion sq m of usable area for solar power, 20% can handle installation of up to 100GWp. China’s desert area is approximately 1.2 million sq km, of which, up to 40MWp of solar power can be installed on each sq km, totaling 1000GW! By 2020, China’s installed desert solar power capacity will reach 200MW.

**Nuclear Energy: Maximizing the Benefits & Multi-Scale Multi-Physics Materials Modeling and Simulation Approach**

Cetin Unal and Sara C. Scott, Civilian Nuclear Programs, Los Alamos National Laboratory, USA.

Al Hurd gave the presentation for Cetin Unal who was not able to be in Suzhou.

Al started the presentation by stating the world needs a Nobel Prize winning breakthrough in energy.

The key challenges in nuclear energy are public perception, investment risk, a decades-old industrial paradigm, waste management, ways to avoid non-proliferation, and to clarify and communicate tradeoffs.

The US Department of Energy Goals are to drive greenhouse gas emission to 20% below 1990 levels by 2020, to save more oil than the US currently imports for the Middle East and Venezuela combined within 10 years, to strengthen non-proliferation activities, and to create new green jobs and lay the foundation for the future.

Los Alamos National Laboratory can help these goals by using its ability to solve complex problems requiring interdisciplinary approaches. It has an integrated programmatic and technical base with a close coupling of computational, experimental and manufacturing capabilities, and real-world
experience in scientific, industrial, and international partnering. It has unique facilities and infrastructure.

... and Our Unique Facilities and Infrastructure

LANL is focusing on Science based solutions for getting the most from the US existing nuclear energy infrastructure including evaluation of new fuel cycle for existing light water reactors, basic science to create advanced materials to withstand higher doses of radiation, and science-based nuclear licensing framework development.

Work on future nuclear energy fuel cycle options include waste management options and ceramic fuels research and development.

They are also looking at identifying risks, impacts, and solutions for global nuclear materials management including new technologies for hard safeguard measurements and detection of clandestine activities, and integrated systems for real-time global nuclear materials management.

Modeling and simulation capabilities for good decisions regarding nuclear energy system options including the discovery and understanding of complex physics problems.

An example is in fuels modeling and simulation.
The tools are in place in multi-program labs like LANL which have the broad technical base needed to make important contributions to energy security and other civilian nuclear needs. They are building on broader programmatic activities to address nuclear energy challenges using linkage between their facilities and computational base. External partnering is an important strategy.

Cross-cutting Programme on Advanced Materials
Frederic Schuster, Commissariat a la Energie Atomique (CEA), France

The speaker began with a description of the structure of CEA. Across the divisions on Nuclear Energy, Technological Research, Military Applications, Physical Sciences, and Life Sciences are cross-cutting projects. A cross cutting program on nanosciences feeds into a cross-cutting program on Advanced Materials which has impact on a number of CEA programs on low carbon energies. These are Gen II, Gen III, Gen IV, and Fusion nuclear programs and new energy technology programs on hydrogen fuel cells, photovoltaics, energy storage, and energy efficiency.

For the advanced materials technologies there is an industrial drive approach that leads to technology transfers and spin off companies. Nanotechnologies and materials have impacts on high performance metallurgy, advanced composites and ceramic, and surface treatment.
The high performance metallurgy program is developing materials for extreme environments and more work is needed in the processing as well as developing resistance to high levels of neutron irradiation and high mechanical strength and resistance to creep.

The advanced ceramics project is looking at SiC/SiC composites for nuclear applications where they have advantages in low neutron activation, good high temperature thermal conductivities and mechanical properties.

Fuel elements are also being studied where plate and pin concepts are being employed.

The nanotechnology programs have a strong emphasis on risk management with the NANOSAFE Project.
<table>
<thead>
<tr>
<th>Year</th>
<th>Project/Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>Risk management – <strong>NANOSAFE project</strong></td>
</tr>
<tr>
<td>2006</td>
<td>Risk management – <strong>INTEGRISK project</strong></td>
</tr>
<tr>
<td>2007</td>
<td>Safe Nanomanufacturing – <strong>SAPHIR project</strong></td>
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<tr>
<td>2008</td>
<td>Life Cycle Analysis – <strong>NANOHOUSE project</strong></td>
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<td>2009</td>
<td>Nanomedicine – <strong>MEDITRANS project</strong></td>
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<td>2010</td>
<td>Depollution – <strong>NANOSECURE project</strong></td>
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<tr>
<td>2011</td>
<td>CNT &amp; Nanostructured polymers – <strong>GENESIS project</strong></td>
</tr>
<tr>
<td>2012</td>
<td>Nanometrology and monitoring – <strong>NANOCARA project</strong></td>
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The indices of socioeconomic development like literacy, longevity, gross domestic product, and human development are directly dependent upon the per capita energy consumption of a country. North America consumes 12000 kWh/annum and Western Europe consumes 6000. The World average is 2200 kWh/annum while India’s is 960 kWh/annum. The energy potential for India lies in nuclear energy, particularly in the thorium fast breeder reactor (FBR).

The nuclear power scenario involves three stages.

<table>
<thead>
<tr>
<th>Energy Resource</th>
<th>Amount</th>
<th>Electricity Potential GWe-yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>53.3 -BT</td>
<td>10,860</td>
</tr>
<tr>
<td>Hydrocarbon</td>
<td>12 -BT</td>
<td>5,833</td>
</tr>
<tr>
<td>Uranium-Metal</td>
<td>94,000 -T</td>
<td>490</td>
</tr>
<tr>
<td>- In PHWR</td>
<td>490</td>
<td></td>
</tr>
<tr>
<td>- In Fast Breeders</td>
<td>64700</td>
<td></td>
</tr>
<tr>
<td>Thorium-Metal (In Breeders)</td>
<td>2,25,000 -T</td>
<td>155,000</td>
</tr>
<tr>
<td>Hydro</td>
<td>150 -GWe</td>
<td>69 GWe-yr / yr</td>
</tr>
<tr>
<td>Renewables</td>
<td>100 GW(e)</td>
<td></td>
</tr>
</tbody>
</table>
There is a renewed interest internationally in FBRs. India intends to produce 21 GWe by 2020 and 275 GWe by 2052. Sodium cooled FBRs have challenges in structural materials (high temperatures and design life of 40 to 100 years), efficiency, and sodium and irradiation environment (inspection and repair).

Materials for FBRs include out of core materials (high temperature sodium), nuclear fuel materials (carbide, oxide, and metallic), functional materials (sodium sensors, Superconducting Quantum Interference Devices for magnetic field measurement, and MEMS), and core structural materials (high temperature, high radiation flux, and sodium).

Radiation causes many defects in the core materials but the overall effect is to make the core swell and this limits the residence time of the fuel sub assembly and increases the unit cost of the power. The addition of TiC precipitates to the fuel helps to reduce the amount of swelling.

The radiation damage in a reactor occurs at various time and length scale and hence multiscale modeling is required. Behavior at each scale directly or indirectly affects other scales and so it is necessary to model simultaneously at all relevant scales.

Experimental techniques at these various time and length scales are also required. These include positron annihilation spectroscopy, small angle neutron scattering, small angle X-ray scattering, in-situ TEM, secondary ion mass spectroscopy, Auger electrons spectroscopy, nano-indentation, and mechanical properties.

A close cooperation between R&D institutes, academic institutions, and industry s required.
For India Fast Breeder Reactors ensure energy security. Core and structural materials must be able to withstand up to a burnup of 100 dpa and up to 40 years lifetime. To increase the power level and burnup, development of advanced innovative materials is essential. Closing the fuel cycle with appropriate reprocessing and waste management is important to make the FBR technology safe, economically viable and acceptable. International co-operation for concerted research is important.

Emerging Materials Issues on Safety and Reliability in Pressurized Water Nuclear Reactors
En-Hou Han, institute of Metal Research (IMR), Chinese Academy of Sciences.

Professor Han started by stating that economic expansion by 2030 will raise the energy needs of the world by a factor of three over those of 1971. The way in which these needs will be met is by nuclear energy.

However, nuclear reactors already in service need a life extension.

There have been several failures (materials degradation) in recent years including corrosion of reactor vessel heads, stress corrosion cracking of steam generator tubing, flow assisted corrosion of primary water pipe, cracking of dissimilar welding, and the cracking of the control rod drive mechanism (CRDM) nozzle.

Emerging materials issues in nuclear reactors are irradiation effects in reactor pressure vessel (RPV) steels and internals, electric cable insulation and aging, concrete exposed to high temperature and radiation and steel bar corrosion, environmental assisted cracking, in situ non-destructive evaluation
new methods, electrochemistry, relation between acceleration test and real lifetime, solidification and precipitation control of heavy steel ingots, and the forging process for irregular and large parts.

As an example of one of these areas the issues for environmental-assisted cracking are simulation and characterization at the atomic scale, fractures in a corrosive environment, fatigue caused by corrosion, welding of dissimilar materials, cold work, surface treatment, crevices between tubes and supporters, influence of small sized defects, high temperature electrochemistry in high pressure water, local film properties, and the role of microstructure.

The author has a large research program

There remain many world-wide important issues that need to be solved to ensure the safety and reliability of nuclear power plants. Any failure in any country will destroy the public’s confidence and affect the nuclear effort; world-wide cooperation is needed. Industry, academe and government must work together to solve the issues and much work needs to be done particularly fundamental research at the nano and atomic scales.

Materials Related to Photocatalytic H₂ Production and H₂ Utilization in PEM Fuel Cell
Liejin Guo, State Key Laboratory of Multiphase Flow in Power Engineering, Xi’an Jiaotong University, China.

China has lots of sunshine, particularly in the west. Two thirds of the country has more than 2200 hours per year of sun equaling 5000 megajoules/square meter. An efficient way to produce energy is use photocatalysis to produce hydrogen by splitting water. Hydrogen has a high energy density, is clean, storable, transportable, and renewable. The photocatalyst should have a suitable bandgap to extend the response in the visible light region, increase the efficiency of charge separation within/at the surface of the photocatalyst, and suppress the recombination of hydrogen and oxygen. Over 130
photocatalysts have been developed up to now at Xian Jiaotong University. The aim is to find materials with visible light response, high efficiency and low cost.

Platinum-loaded cadmium sulphide (CdS) is among the most studied showing high activity for H₂ production but CdS like other sulfides is prone to photo corrosion in the photocatalytic reaction. Various methods have been attempted to further enhance its activity and improve its stability. CdS nanoparticles were decorated on a Na₂Ti₃O₄(OH)₂ nanotube. This showed improved photocatalytic activity under visible light because of its large surface area and because the special 1D structure of the nanotube promotes transfer and separation of photo-generated electrons.

CdS was also used to decorate a lamellar structure photocatalyst (CdS/HTiTaO₅). The author’s method using high temperature treatment improved the crystallinity of the structure.

A new technique encapsulated CS nanocrystallites into the mesopores of the zeolite Ti-MCM-41 and the absorption edge was blue-shifted compared to that of the bulk particulates. Pt-loaded composite photocatalyst had much higher activity for H₂ production than its bulk counterpart.

Also studied were CdS/ZrₓTi₁₋ₓPO₄ (quantum yield 27.2%, energy efficiency 7.16%) and a CdS special morphology.

**Materials Challenges for Solid Oxide Fuel Cells**
Subhash C. Singhal, Pacific Northwest National Laboratory, USA

The advantages of solid oxide fuel cells are their high electric conversion efficiency and environmental performance (no SOₓ or NOₓ, lower CO₂, quiet and vibrationless) and produce exhaust heat that can be used for heating, cooling, or additional power generation. Because of their high operating temperatures (600°C to 1000°C) they have fuel flexibility (natural gas (liquefied, pipeline, or coal), methanol, naphtha, and biogases) compared to polymer fuel cells that operate in the 90 to 120°C range. They can be made in many sizes and sited in many places. The market drivers are these advantages but the negatives are the cost, the lifetime and performance degradation.
A fuel cell is composed of several layers.

The selection criteria for the materials comprising those layers are chemical stability at high temperatures, suitable electrical properties, and minimum reactivity, interdiffusion, and thermal expansion differences among the layers.

The performance of a solid oxide fuel cell is dominated by the polarization effects that occur at both electrodes. The cathode polarization usually dominates in SOFCs.
Cathode materials reduce the oxygen to oxide ions. Typical cathode materials are:

- [(La,Sr/Ca)MnO$_3$, lanthanum strontium manganite (LSM)/yttria stabilized zirconia (YSZ), Ca-doped LaMnO$_3$ (LCM)/YSZ],
- [(La,Sr/Ca)(Co,Fe)O$_3$, (Ba,Sr)(Co,Fe)O$_3$, and (Sm,Sr)CoO$_3$],
- (La$_2$NiO$_4$).

The perovskite La$_{1-x}$Sr$_x$Co$_{1-y}$Fe$_y$O$_3$ has good performance but low performance stability. LSM provides greater performance stability. In these materials the triple phase boundary length can affect the cathodic voltage loss, so it is important to keep the grain size small.

The electrolyte is required to have high oxide ion conductivity with the transport number for oxygen ions close to unity and for electrons close to zero. It must not allow gases to permeate from one side to the other while being uniformly thin to minimize ohmic losses and uniformly doped to reduce thermal expansion differences. Zirconia-based electrolytes are widely used.

The anode materials must have good chemical stability in the reducing environment of the fuel, must be electrically conducting (more than 100S cm$^{-1}$), must be adherent to the electrolyte, have interconnected pores, and be able to reform and directly oxidize hydrocarbon fuels. Materials used for anodes include nickel (or cobalt, or ruthenium)/YSZ cermet, non-nickel cermets to prevent carbon forming from hydrocarbon fuels, and conducting ceramics such as (La,Sr)(Ti,Ce)O$_3$. Also used are oxide materials such as perovskites (LaFeO$_3$, SrTiO$_3$, LaCrO$_3$, LaMnO$_3$, (La,Sr)(Mn,Fe)O$_3$, La$_2$Mo$_2$O$_9$, and Sr$_2$Mg$_{1-x}$MnxMoO$_6$. The Ni/YSZ is the most widely used. The ceramics are not as good.
Seals and interconnects are critical. Sealing materials must prevent the mixing and leaking of fuel and oxidant and they must electrically isolate the cells in the stack while providing mechanical bonding. Also they must be structurally stable, be chemically compatible, and inexpensive. Glass or glass-ceramic seals (BaO-Al₂O₃-SiO₂) are often used. The requirements are 40,000 hours (5 years).

Interconnect materials require very high electrical conductivity, stability in reducing and oxidizing environments, thermal expansion matches, non-reactive with the air electrode and electrolyte, low oxygen and hydrogen transport through the film, and low cost. Doped LaCrO₃ is often used but Cr contamination in the cell is bad. There is a need for effective coatings to reduce Cr contamination.

The major impact of nanotechnology on solid oxide fuel cells is to improve the ionic conduction in the electrolyte, improve electrocatalysis by decreasing grain size (increasing surface area) and optimizing conduction paths in the electrodes and sinterability of the seals.

The major challenges are the stabilities of the cathode at high temperatures and the anode during cell fabrication and operation. An additional challenge is to lower the operating temperature of the cell to take advantage of the beneficial effects of nanotechnology.
Hydrogen is an excellent candidate for long driving range renewable fuel systems. The weight and volume for a compressed hydrogen power source lies between diesel oil and Li-ion batteries.
The requirements for hydrogen storage for mobile application are low weight and volume, a driving range of 500 kilometers, a refueling time of less than 3 minutes with no external cooling during refueling, a lifetime of at least 500 cycles, and low material costs.

A further improvement would be the storage of hydrogen in light-weight solids. Here sorbent systems for hydrogen look very promising. Physiabsorption is completely reversible and has fast kinetics but does require low temperatures. Metal-organic frameworks (e.g. MOF-5) of \( \text{Zn}_4\text{O(CO}_2\text{)}_6 \) subunits connected by benzene rings with \( \text{CO}_2^- \) ions create “Nanocubes” and have some of the largest specific surface areas and highest hydrogen storage capacities.

Therefore, these materials with large specific surface area give rise to a high storage capacity at low temperatures (77 K), whereas the pore size is mainly determining the heat of adsorption. The future lies in the synthesis of novel materials with large surface areas in which it will be necessary to find the optimal pore size or composition.
Dr Züttel started with a history of energy use.
And went on show how the world’s energy consumption has skyrocketed.

Oil is about to reach its peak as an energy source and there is growing gap between oil discovery and consumption and the price of oil reached $150 per barrel in 2008 and is likely to reach or exceed that again in the future. He went on to describe the energy efficiency paradox where the amount of energy used goes up as the use of energy becomes more efficient.

In describing the various energy sources available to mankind, Dr Züttel showed how the entire planet’s energy needs (120 terawatt hours/year) could be met by the effective collection of the solar power falling on a surface area equal to that of Switzerland.

He showed that batteries are unaffordable in cost, size and weight for automobiles and airplanes so that hydrogen energy use looks like the only solution. Hydrogen can be stored as gas or liquid. It can be physically absorbed or stored as a hydride of metal, as a complex hydride, or as a chemical hydride.

There are many materials for hydrogen storage with different volumetric and gravimetric densities.
Synthetic hydrocarbons can be made using the sun’s energy and electrolysis. The watergas-shift-reaction can form CO from CO$_2$ and H$_2$ and the CO can in turn be converted to carbon-hydrides by the Fischer-Tropsch synthesis.
Progress on Redox Flow Battery (RFB) for Energy Storage
Huamin Zhang, Dalian Institute of Chemical Physics (DICP), Chinese Academy of Sciences

The world is in need of an effective means for storing energy. Both wind and solar generated power is intermittent in nature and need energy storage as does the smart grid to improve electricity utilization efficiency by improving load leveling and stability.

There are a number of ways of storing energy.

**Various Scale Energy Storage Technologies**

- **Proper methods for large scale ESS:**
  - **Physical ESS:** compressed-air ESS, pumping-hydro ESS
  - **Chemical ESS:** lead-acid battery, NaS battery, redox-flow battery
One system that shows a great deal of promise is the Redox-Flow Battery (RFB). RFB electrochemically stores and releases energy by the valence change of the active species in an electrolyte that circulates through an anode and cathode, which are separated by an ion-exchange membrane.

The advantages of RFB are that it has large independent power and capacity, high energy efficiency (more than 75%), long lifetime (more than 15 Years), ability to deep discharge, and low self-discharge. It is also environmentally friendly and safe.

Applications include back up power, power sharing for the smart grid, electric vehicle charging stations, remote area power sources, telecommunication, and storage for intermittent systems like wind and solar.

Although many successful demonstrations have been carried out, there are still some challenges for the VRB commercialization. These include low concentration and unbalance of the electrolyte, low current density and high cost. These challenges arise from the materials used in the electrolyte (stability and solubility), the ion-exchange membrane (stability, durability, selectivity, and cost), and the electrode and bipolar plate (activity, electrical conductivity, anti-oxidation, and cost).

Professor Zhang’s group has made progress on modifying a Nafion membrane surface with cation layers on both sides to stop vanadium ions from passing through. It has superior performance to a composite
membrane. This has enabled them to go from a single cell in 2000 to 10kW system in 2005 (81% efficiency) to a 100kW system in 2008 (75% efficiency). This is the largest Redox flow battery in China. They have demonstrated a 200kWh system on the national grid and are installing a 300kWh independent power supply for an office building in Dalian.

Materials Challenges for Sustainable Energy
George Crabtree, Materials Science Division, Argonne National Laboratory, USA

Oil and carbon dioxide represent the world’s major sustainability challenges. 40% of global energy is supplied by oil; demand is rising for this finite resource and a production peak is expected before mid-century, producing increasing competition and geopolitical tension over energy shortfalls. Left unchecked, greenhouse gases could destabilize the climate, causing permanent changes to weather patterns, agricultural networks, and coastal geography. The cost of dealing with climate change after the fact could be much higher than the preventive cost of reducing emissions.

Sustainable energy technologies have achieved little penetration because they are significantly more expensive than fossil fuels. Dramatic improvements are needed in sustainable technologies to lower their cost by understanding and controlling materials and chemistry at the molecular and nanoscale levels.

The sustainability of an energy technology depends on at least three criteria; the energy source must last a long time, the technology must do no harm to climate, environment or human health, and, in the best case, it must leave no change to the biosphere of the earth. Solar electricity is exemplary in satisfying these criteria (though the impact of constructing the required infrastructure must be considered). Roadblocks to its widespread deployment are the high cost of solar electricity compared to fossil, and the need for large-scale storage to bridge gaps in the supply-demand cycle.

Carbon sequestration gets a high sustainability score for reducing carbon emissions, but a "wait and see" score for geologic storage, where chemical reactions with diverse underground rock environments are not understood, and where leakage to the surface must be tightly controlled in order to achieve containment for thousands of years. Coal will last hundreds of years, longer than oil but not as long as the sun, and sequestration leaves significant changes in the earth as coal is removed and carbon dioxide
is injected underground. Breakthroughs needed include understanding chemical reactivity with rocks in extreme environments underground, modeling and prediction of migration through porous rocks, and controlling leakage routes to the atmosphere.

Nuclear electricity, like carbon sequestration, prevents carbon emissions, but at the cost of storing spent nuclear fuel underground, which must be stabilized, monitored and controlled for thousands to hundreds of thousands of years depending on the storage scheme. Modern reactors can operate at high efficiency, minimizing their number, cost, and lifecycle impact, if materials capable of withstanding the multiple extreme environments of high temperature, high radiation flux, and high corrosivity can be developed. Geologic modeling and prediction of the future decay and degradation of the spent fuel and its storage media are needed.

Electric transportation has the potential for a high sustainability profile if batteries with 2 to 5 times higher energy density can be developed, and if large scale renewable electricity sources needed to replace the gasoline-driven vehicle fleet can be achieved.

Electricity storage is required not only for electric vehicles but also for leveling wind and solar electricity supply cycles. The enormous gap between energy storage densities of the best batteries now available and of gasoline and ethanol (see figure) can be filled by developing electro-chemical storage media that convert the high energy density of chemical bonds to the versatile, clean and efficient energy of electrons.

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**Enabling Technologies: Storing Energy**

- Store intermittent solar and wind electricity
- Electrify transportation with plug-in hybrids and electric cars

![Image showing energy storage technologies]

- Breakthroughs needed: x2-5 increase in battery energy density
  x10-20 increase through chemical storage + fuel cells
It is likely the world will need most or all of the available sustainable energy alternatives. Because sustainable energy technologies are in their infancy (like the steam engine in James Watt’s day), we do not know which will emerge as the most effective. Economics and market inertia will delay deployment, providing time to develop the advanced materials and chemistry needed to raise the efficiency and lower the cost of sustainable energy technologies.

The sustainable energy chain requires complex, high tech, long lifetime materials that are valued for their sophisticated energy conversion functionality, very different from the traditional energy chain where the important materials are simple fossil fuels that are found naturally and valued for their low cost and high energy content.

**The Transition to Sustainable Energy:**

**High Tech Materials and Chemistry**

The sustainable energy challenge is developing the sophisticated, high tech materials and chemistry that will allow alternative energies to compete with low cost fossil energy. The magnitude of the challenge is illustrated by the three decades of effort since the first oil crisis that has not produced significant penetration of sustainable energy. Science is now equipped to meet the challenge, using a decade of rapid progress in nanoscience and nanoscale materials, in high performance computing and in creating and controlling complex materials. Meeting the challenge requires “Dream Teams” of the best scientists working with the best tools and focused on the most important problems. The Basic Energy Sciences Energy Frontier Research Centers are launching some of these teams as an essential first step.
We must also launch an aggressive program to recruit and train the best and the brightest students and early career scientists. A massive and sustained investment in materials and chemistry for sustainable energy is needed immediately to achieve the breakthroughs needed for next-generation energy technologies.

Further reading

*The Road to Sustainability*, George Crabtree and John Sarrao, Physics World 22(10), 24 (2009).

**Low CO₂ Footprint Batteries**
Michel Armand, Laboratoire de Réactivité et de Chimie des Solides, Université de Picardie Jules Verne, Amiens, France.

The growth in oil demand over the next 20 years will mainly come from transportation. The effect of the use of fossil fuel on the world’s climate has been known for a long time. Shen Kuo (沈括) (1031-1095), Song Dynasty stated that the climate has changed in the past, while Joseph Fourier (1768-1830) told us that gases from the atmosphere of Earth increase the surface temperature (greenhouse effect). Svante Arrhenius (1859-1927) said that if the quantity of carbonic acid increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression ($\Delta t = \alpha \ln(C/C_0)$).

In order to reduce the effect on the atmosphere it will be necessary to develop electric vehicles but only lithium batteries, will be able to meet the needs.

Armand talked about the efficiencies of three ways that solar can be used to create fuel. The first is solar electric to battery (EV). Incident sunlight to a solar plant (15%), power line to the home (93%), and plug to wheel (72%) for an overall efficiency of 10%. The second is solar electric to hydrogen. Incident sunlight to a solar plant (15%), H₂ compression and transport (60%), fuel cell efficiency (60%), electricity
form fuel cell to wheel (91%) for an overall efficiency of 2.5%. The third is Agro-bio fuels. Incident light to biomass (0.3%), biomass to fuel at the pump (10 to 70%), from tank to wheel (ethanol 18%, biodiesel 23%) for an overall efficiency of 0.054 to 0.48%. Clearly batteries are the way to go and the future lies in gel or ionic liquid lithium batteries with higher capacity.

Electrode materials have gone through an evolution of their own.
Oxides have proven to have safety issues as the problems with laptop computers catching fire will testify.

The lithium battery chemistry with LFP is ready and is the only viable system for the short term. There is no miracle coming soon for the 100km driving range per 100 Kg of battery and there no possibility to hope for generalized fast charging. Calculations for the French network for 8 hours recharging (one million stations) will cost 3 billion Euros, while implementing 10% of fast charge stations in big cities will cost 18 billion Euros).

Ionic liquids offer an extraordinary medium for low CO2 footprint electrode synthesis and novel systems. The next targets are LiPF6 and graphite/copper tandem while organics are a possible substitute for all electrode materials alone or mixed (composite mechanical properties)
The energy consumption of China has risen by almost a factor of two since 2001 and 20% of this is oil of which 50% must be imported. That together with the associated air pollution has led China to return to the use of biomass fuels. This is shown by the blue arrows in the following figure.

China is not willing to use foodstuffs or crop residues to produce fuel so the raw materials for bio-energy in China are non-food-based materials such as cassava and sweet sorghum, residues of agriculture (cellulose), and waste from industry and cities. 620 megatons of straw are produced annually.
Crop residues are utilized in the following way.

Biodiesel is expected to make a great deal of progress in China. Raw materials such as the oil plants Jatropha and Chinese pistache could produce 5,000,000 tons of biodiesel every year while waste oil and fats could produce 2,000,000 tons. Recently many biodiesel factories with outputs more than ten thousand tons have been established in China.

The production methods are chemical and enzymatic conversion, and a high pressure method. Most factories use the chemical conversion using traditional alkali as a catalyst (100,000 t/a) but this has waste water problems and high energy consumption (200°C). Enzymatic conversion produces low pollution and is environmentally friendly. It can be used on any oil of fats.

Raw materials for biodiesel include 1 million tons of waste oil, oil trees (Mafeng tree), and oil from microorganisms and microalgae.

Microbial fermentation can convert sugar-abundant waste water into lipids and does not release carbon into the atmosphere. It is possible to produce one million tons for lipids per year by this method.

China has launched a national program for ethanol bio-fuel production and is committed to expand fuel production to more than 10 million tons/year by 2020. In the Pilot Phase from 2000-2005, four plants were built to produce fuel ethanol from corn, with total capacity of 1.02 million tons per year. PetroChina and Sinopec are responsible for blending fuel with gasoline, distributing and selling gasohol (E10) as fuels for road transport in 9 provinces. Fuel ethanol producers enjoy favorable policies, including free income tax, VAT refunding, fiscal subsidies. By 2005, gasohol consumption accounted for nearly 20% of the national gasoline consumption.

A high value straw resource eco-system has been developed as well as corn cob refinery technology.
Hydrogen has also been produced from organic waste and an industrial demonstration includes hydrogen production by fermentation, purification, and secondary water treatment for an annual yield of 400,000 m$^3$/year of 99.9% pure hydrogen (Tsinghua University fuel cell group participated). Biogas is produced by anaerobic digestion together with organic fertilizer. This is especially employed in rural areas.

Energy has also been produced by pyrolysis where a new type of rotary core reactor with a capacity of 200kg/hr has been developed by Northeast Forestry University.

Bioethylene and other chemical have been produced by catalytic reaction in ethanol. 200,000 tons/year of acrylamide are made in China with 99.9% conversion efficiency and a cost per ton of less than 80 RMB.

Lactic acid is also made in a number of plants in China and some polyhydroxyalkanates (PHA) together with 1, 3-Propanediol, used in polymer polymerization. Long chain dicarboxylic acid C10–C18 is also made by bio-transformation which is easier than by chemical synthesis.

China intends to strengthen its bio-based energy and materials during the 2010-2015 timeframe. Bio-refineries are expected to produce a billion tons of super critical carbon dioxide extraction (SCE) in the future and reduce the emission of greenhouse gases by 200 million tone every year. The income of farmers will be increased by 45 billion RMB.
Delivering on our 2010 Promise
Mars Zhu, Novozymes, China

Novozymes is the world leader in industrial enzymes & microorganisms and a market leader in all the industries where it is present. It has more than 700 products used in 130 countries in 40 different industries and R&D activities in 5 countries. 13-14% of its revenue is invested in R&D and new products represented around 25% of total sales in 2008. It has more than 6,000 granted or pending patents and 43 new products launched during the last 5 years.

Novozymes is the world leader within the development of technologies for bioethanol. With enzyme technology it is possible to use the different components of biomass for different purposes. Biomass contains starch, which can be used for food, feed, or for production of what is called first-generation bioethanol. When it contains protein, which is used as food or as animal feed, it also contains cellulose, which from 2010 will be used for the commercial production of second-generation bioethanol. The last component is lignin, which is (at present) is best suited for combustion. Careful planning will allow all the elements of biomass to be utilized with very little waste. In 2010 second-generation bioethanol will offer energy made from waste or from energy crops that can grow where little else can grow.

Production costs are falling to the point where they are feasible.
Enzyme costs are becoming a smaller percentage of the total process costs. Novozymes’ new product family is the first step on our path to delivering on Novzyme’s promise of commercial viability by 2010. Through partnerships they expect to advance enzyme and process technology to enable commercial viability of ethanol from biomass by 2010.
Fossil fuels are solar energy and today the liquid fossil fuel is known as petroleum. The ancient Persians used it for lighting. The Chinese drilled the first “oil wells” almost 2000 years ago up to 240 meters deep. The first U.S. well (21m deep) was drilled by Edwin Drake in 1859 in Titusville, Pennsylvania.

Now the future energy source is the sun directly because the sun will be with us for a long time (2 to 3 billion years). It is also a very powerful source of energy. Enough energy reaches the earth from the sun in an hour to supply human needs for a year (16 terawatts a year). By 2020 those needs will reach 20 terawatts per year. A major reason the sun is the perfect source of energy is that it is available to all nations. No one owns the sun.

The ways of capturing the sun’s energy are by electricity, heat, and biomass. Electricity can be generated by means of photovoltaics which are approaching 20% efficiencies using copper indium gallium selenide polycrystalline thin films together with the addition of zinc oxide and cadmium sulfate. Cleantech America is planning California’s first utility-scale photovoltaic solar project (5MW) to be approved under the state’s Renewable Portfolio Standard (RPS) program.

Another means of capturing the sun’s energy is solar thermal electricity generation. Focusing the sun’s rays on oil creates high temperatures that are used to generate steam for a turbine with 20% efficiency. A single solar dish-Stirling engine at Sandia Laboratories has produced 25 kW of electricity at 31.25% efficiency.

Germany, Japan, Australia, Algeria, Israel, China, the U.S. and many others are developing solar energy. A 1 gigawatt solar farm is planned for Qinghai province in China as well as other farms in Yunnan, Jiangsu, and Zhejiang provinces.
The sun can be used to provide thermal energy for swimming pools or residential hot water to offset the
25% of energy used in commercial buildings and 50% of the energy used in residential buildings. Solar
lighting in the form of solar tubes is also under development.

Biomass production uses the ancient photosynthesis process to directly convert carbon dioxide into
organic compounds like sugars. 100 terawatts of solar energy is captured each year by photosynthesis.
Photosynthetic energy in the form of biomass can be used for liquid fuels, thermal energy, and fuels
such as hydrogen. Plants are virtually the initial chemical processing factory.

While we have over the past two centuries been able to produce enough biomass for food, fiber, and
energy needs the potential is not unlimited. Land requirements, water, and various plant nutrients
would become limiting factors. Biomass utilization requires that we do the definitive research first.

Many potential energy crops are perennials and do not require annual tillage of the soil. They help
conservation of soil and water. Examples of such a species are elephant grass, miscanthus, and
switchgrass.

The Green Revolution has made progress in capturing the sun’s energy for food and, over the years,
several bioproducts and coproducts have been developed including a superb natural latex rubber from
the U.S, native shrub guayule (parthenium argentatum). Such bioproducts lessen the demand for oil. A
major byproduct in the process for converting corn grain to ethanol is distillers dried grain (DDG) which
is an excellent feed (30% protein and 30 to 40% fiber) for monogastric animals. Zein (prolamine protein)
is another important bioproduct from corn gluten meal and is used in adhesives, binders, and film. It is
making a comeback now that oil is no longer cheap.

Sugar beet is now being used to make polylactic acid for thermoplastics which are biodegradable and
the tung tree, native to China, is capable of making fatty acids. The Statue of Liberty in New York
harbor uses soy-based hydraulic oil.

Biofuels for transportation is a pressing need. Brazil is using sugarcane to produce ethanol and is using
this to achieve sustainable energy security. The U.S. has been successful in the use of corn to become
the leading producer of ethanol (9 billion gallons in 2008). The U.S. Department of Agriculture Research
Service (USDA-ARS) has created a new enzymatic process that gives higher levels of starch and reduces
production costs.

One of the most exciting developments in ethanol production is the Advanced Solid State Fermentation
technology using sweet sorghum stalks developed by Prof. Shi-Zhong Li in Tsinghua University, P.R.China.
A short and simple process minimizes sugar conversion, requires less energy and water and the residue
can be used for cattle feed.

In the U.S. in the future, bio-refineries will use advanced technology such as acid hydrolysis of cellulosic
biomass with the resulting 5 or 6 carbon sugars fermented into alcohol or thermo-chemical conversion
of biomass to synthesis gas and catalysis to biopolymers.
There must be an unprecedented commitment to research. Some fruitful areas of research include expansion of the collection of species that can be used for biofuels, improving the breeding systems for perennial C4 grasses, evaluating species in the ARS National Germplasm Repository for desirable energy potential, identification of new and useful species of plants for energy and suitable herbicides, identification of pests, pathogens, and pesticide management practices for energy crops, and long term storage. Also develop crops that accumulate only sugar or starch e.g. sugarbeet, sugarcane, or sweet sorghum for sugar and potato and cassava for starch.

The obvious conclusion is that the sun is an ideal source of energy for the benefit of mankind. All mankind has no alternative but to engage in developing methods to capture its energy.

**State of the Art of Biomass Liquid Fuel in China**
Hailong Lin, COFCO Corporation, Beijing, China

Fuel ethanol use is confined to a limited number of areas in China.

In 2007 the total China capacity was 1.4 million tons of which the COFCO market share was 45%. In 2008 the China capacity had risen to 1.5 million tons and COFCO’s share to 52%.
There is a three step roadmap for the development of ethanol. The first in 2007 involves the use of corn and wheat which in 2008 moves to cassava and in 2009 to lignocellulosic agricultural residues, forestry residues and other biomass. The industry moves from grain-based to non-grain-based.

The cassava ethanol facility run by the Guangxi COFCO Bio-energy Co., Ltd of Beihai, Guangxi in a joint development with Tianjin University is the first facility to use cassava. It produces 450 tons per day of ethanol and 60000 Nm$^3$ per day of biogas.

COFCO and its partners have been engaged in sweet sorghum fuel ethanol technology development from 2007 to 2008. An agronomy trial was conducted with BP and the Hebei Agro-Science Institute, A solid fermentation pilot trial with Tsinghua University, a liquid fermentation pilot trial with the Guangxi Science and Technology Institute for Light Industry, and a finishing feasibility study of 30 kilotons per year liquid fermentation project.

Lignocellulosic ethanol work has been conducted at a number of institutions.

The Institute of Process Engineering, CAS has worked on steam explosion pretreatment, cellulase solid fermentation, and straw solid fermentation process and equipment.

The State Key Lab of Microbial Technology, Shandong University has been doing screening and mutation of cellulase-producing strains and improvement of enzyme yield while East China University of Science & Technology is developing a sawdust ethanol (600t/a) pilot facility using dilute hydrochloric acid pretreatment, catalytic (FeCl$_2$) hydrolysis, and glucose/xylose fermentation.

Zhejiang University is producing alcohol from agriculture fiber waste with a pilot trial in Hebei using corn cob as feedstock and obtaining an ethanol yield 22.2% in weight.

Jilin Province Light Industry Design & Research Institute has a wet oxidation pretreatment for corn stover (leaves and stalks) ethanol production giving an enzymatic hydrolysis of 86.4% and an ethanol yield of 48.2%.

Henan Agricultural University is using a biological pretreatment (\textit{P.chrysosporium} & \textit{Coriolus Versicolor}) and Nanjing Forestry University employs a corn stover ethanol pilot facility, with batch steam explosion, enzymatic hydrolysis and C5/C6 co-fermentation. The hydrolysis yield is 71.3%with a sugar utilization of 87.17% and an ethanol yield of 0.43%.

Finally the Chinese Academy of Sciences has set up a cellulosic Ethanol High-Temperature Fermentation and Bio-refinery with several themes:
Theme I: Research on Lignocellulose Pretreatment Technologies;
Theme II: Discovering, Restructuring and Applying of New Lignocellulose Catabolic Enzymes;
Theme III: Systematic Restructuring of High-Temperature Ethanologen with Biotechnologies;
Theme IV: Optimization and Control of Cellulosic Ethanol Fermentation Process

Other organizations involve in second generation fuel alcohol are Henan TianGuan Fuel Ethanol with a 3000t/a straw ethanol and cellulase facility using Batch Steam Explosion Pretreatment and yielding 44.5% of sugar and 45% of ethanol.

The BBCA National Engineering Research Centre of Fermentation Technology is developing a straw cellulose conversion technology. The Huaibei Zhongrun Bioenergy Technology Development Co., Ltd is
also involved in technology development and Jilin Fuel Alcohol uses corn stover in an ethanol pilot/demo.

Shandong Longlive Bio-Technology has xylitol production using feed stock (corn cobs) in an acid hydrolysis process. Ethanol is made using corn cob residue (60% cellulose) in an enzymatic hydrolysis process (80% conversion) and an ethanol yield of 250 kg/t residue.

A COFCO project has operated a 500 tons per year corn stover plant since 2006 co-developed with Novozymes & SINOPEC for pretreatment, cellulase development, and technology integration.

7 DMT of Corn Stover is used for each MT of Ethanol. The parameters of the process are:

Steam explosion temp: 180-220 °C ; Treatment time: 5-10 min
Enzymatic hydrolysis: 48 -52hrs; Cellulose Conversion Rate ≥90%
Fermentation: 36 hrs; Sugar Conversion Rate ≥95%
Ethanol: 7% (v/v) ; Residual Sugar ≤ 0.2%
Bio-diesel in China has technology innovation coming from Beijing University of Chemical Technology with an Immobilized Enzymatic Catalysis Process, the Research Institute of Petroleum Processing, Sinopec developing a Critical Alcoholysis (SRCA) Process, ready for a demonstration plant, and ENN Group working on an algae bio-diesel pilot trial. In addition SINOPEC and CAS are collaborating on algae bio-diesel development. Other institutions involved in research are Tsinghua University, University of Sciences & Technology of China, China Agricultural University, Chinese Academy of Agricultural Sciences, Chinese Academy of Forestry and others.

The road ahead for biomass liquid fuels involves pilot plants (continuous and stable operation, reduction of cost, approval and subsidies from government), demonstrations (engineering design packages, construction of demo) and commercial realization (technology integration, large scale popularization).

Lightweight Vehicles through Advanced Materials
Robert F. Singer, University of Erlangen, Germany.

For automobiles, weight, energy, and emissions are coupled. The weight of cars has increased by 60% over the last 30 years to the point where a further weight increase in cars of 100 kg results in additional consumption of 0.5 liters of fuel for 100 kilometers range and additional emission of 11gm/km of CO₂. The allowable expense for weight reduction is usually valued at 5€/kg of vehicle. There is a lot of pressure from the European Union on the manufacturers to reduce the CO₂ emissions to 137 g/km by 2015 and this may push the allowable expense up to 15€/kg.
The switch to electric cars will increase the pressure on the weight of the vehicle because lithium batteries have only one sixtieth of the storage capacity by weight of gasoline. The solution is to reduce the weight of vehicle body. A recent demonstration car (at a total weight of 260 kg) was able to consume only 0.89 l/100km. The use of batteries will push the allowable expense for weight reduction further up, to 15€/kg or even higher.
Fibre reinforced polymer has the advantage of weight, stiffness, strength, crash energy absorption, and corrosion resistance. However, there are challenges to its use. The autoclave processing is too slow and the injection molding damages the fibers. The solution is the use of integrated forming and injection molding.

Magnesium has the advantages of weight and the ability to be cast but it is costly and not very stiff and its strength at elevated temperatures is suspect. Injection molding with the addition of particle and fibers can solve these limitations.

Metal foams have weight, stiffness, strength, and crash energy absorption advantages. They also absorb sound and vibration. They are difficult to inflame and they provide heat insulation. They also are costly, are difficult to prepare in intricate geometries, and have issues with cell size and uniformity. The solution here is pressure integral foam molding.

Smart die castings also provide advantages of weight savings through piezoelectric sensor and actuator devices, the avoidance of traffic congestion through imbedded systems, and cost savings through RFID’s. The challenge is to integrate the modules into the metal components and the solution is die casting with use of wire cloth to position them.
In summary, weight reduction in vehicles is urgently required because of added cost, harmful emissions and limited resources but new materials technologies abound.

Development of High Performance Thermoelectric Materials and Devices - A Component of the Comprehensive Solution to the Energy Crisis
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Thermoelectricity is the direct conversion of heat into electricity. It is based on the Seebeck, Peltier, and Thomson effects which were discovered a long time ago. The applications potentially are in large scale refrigeration and waste heat recovery, and in solar energy harvesting. On average 60% of energy in industrial processes becomes waste heat so that even 10% capture of this heat will have huge impact. Potential targets are automobiles and trucks, incinerators, and industrial plants.

In today’s internal combustion vehicles less than 20% of the fuel energy is used for propulsion and more than 60% (waste heat) is not used. Applying thermoelectric generators to the exhaust system will recover much of this energy.

Thermoelectric generators can also be used in combination with solar cells to increase the wavelength range of solar power generation.
Thermoelectric performance can be improved by making ZT as high as possible where Z is the thermoelectric figure of merit and T is the absolute temperature.

\[ ZT = \frac{S^2 \sigma}{\kappa T} = \frac{PT}{\kappa} \]

(S = Seebeck coefficient, \( \sigma \) = electrical conductivity, \( \kappa \) = thermal conductivity and P = power factor)

ZT has improved over the years from 0.2 in 1950 to 2.5 in 2007. Skutterudites (SKTs) such as \( \text{Ba}_{0.24}\text{Co}_4\text{Sb}_{12} \) have ZT values of 1.1. They consist of a Cubic structure with eight MX₃ groups in the unit cell and have outstanding electronic properties (high carrier mobilities) but their thermal conductivity is also too high.

Fortunately, the structure offers a possibility to lower thermal conductivity by way of filled skutterudites. The filling factor is controlled by the competition between the filled phase and possible secondary phases. Na and K have a maximum filling fraction (up to 65%) among all reported filled SKTs. Sodium-filled \( \text{Na}_x\text{Co}_4\text{Sb}_{12} \) shows the highest power factor among all single filled SKTs, and relatively high ZT through electron mobility enhancement. Multiple element fillers can do even better. Ba-Yb dual-filled CoSb₃ reaches ZT~1.36@850K, best among the CoSb₃-based bulk materials. Thermoelectric properties including thermal conductivity are sensitively dependent on the microstructure.

**Concept of PV-TE hybrid system for power generation**

A low cost hybrid system could be achieved by integrating concentrator solar cells and TE devices into the same one tracking system, one focusing system and one inversion system.
New processes for fabricating composite materials include in-situ nanoparticle formation plus SPS, melt-spinning (MS) plus SPS, mechanical alloying (MA) plus spark plasma sintering (SPS) (or hot pressing (HP)), and phase segregation. These methods have led to improved results.
Complex chalcogenides such as AgPb$_{18}$SbTe$_{20}$ are outstanding n-type materials with ZT $\sim$ 1.7 at $t = 700K$.

Key issues in TE device design and fabrication are efficiency, stability and reliability. Efficiency is given by high ZT materials over a wide range of temperatures with good interfacial design to control interfacial thermal and electrical resistance and a good match of the thermal and electrical load. The stability and reliability is controlled by the bonding strength and structural design, by the thermal and chemical stability under stress and the materials degradation during processing and operation.

CoSb$_3$ is joined using MoCu alloys and an inserted Ti-interlayer. The coefficient of thermal expansion of the can be tuned by changing the Mo-Cu alloy composition. Mo$_{50}$Cu$_{50}$ shows close CTE values with skutterudite over the whole temperature range 400 to 900K.

Antimony (Sb) diffusion from the chalcogenides can cause intermetallic compounds at the bonding interface which leads to degradation.

Realizing the wider application of TE technology will require efforts in TE engineering while continuing scientific efforts on further improving the ZT value. TE engineering needs not only the contribution from TE materials scientists/engineers but also the contributions from scientists/engineers from other fields, such as metallurgy and electrical and mechanical systems.
By 2007 the carbon released into the atmosphere by the combustion of fossil fuel had reached 8.74 gigatons (31 gigatons of CO$_2$). Methods must be found for removing carbon from the atmosphere.

In order to start the capture of CO$_2$, the EEC has decided to develop 10 industrial plants at a total cost of €12 billion. The goal is to scale up where each plant captures 5 million tons of CO$_2$ per year.

There are several methods for removing CO$_2$. One of these uses adsorbing beads which are able to achieve 89% of CO$_2$ recovery with 99% purity. This purified CO$_2$ can then be sequestered. The cost is $20 to $30/ton.

Sequestration which is the present solution of the European Commission can be accomplished using the production of hydrogen from water and then using this to reduce CO$_2$.

One method proposed is to sequester carbon dioxide in oil fields to enhance oil recovery. A plant is in operation in Mongolia. China’s biggest coal producer, Shenhua Group, proposes to capture and sequester 3.6 millions tons of CO$_2$ per year in oil reservoirs where the pressure of CO$_2$ will force the oil to the surface.

Another method for removing CO$_2$ is to use chemical processes for the production of synfuel and energy storage. Hydrogen can be used to reduce CO$_2$. Catalysts are required for CH$_4$, CH$_3$OH, Syngas, and Fisher-Tropsch synthesis. Also many kinds of catalysts are required to make polymers and other chemicals.

Nickel is the main catalyst for hydrogenation (CO$_2$ $\rightarrow$ CH$_4$) and the Fisher-Tropsch processes. This includes Ni on Al$_2$O$_3$ which is due to spinel shells NiAlO$_4$ and Ni on ZrO$_2$ stabilized by Ce or Pr (tetragonal). However for CH$_3$OH or DME, ZrO$_2$ monoclinic + Ce as a catalyst in cubic structure is used and also Ni/ZrO$_2$ doped with Ce and Co-Fe spinel mixed oxides as Fisher-Tropsch catalyst very active for CO/H$_2$ or CO$_2$/H$_2$ reactions.
For the CO\textsubscript{2} to CH\textsubscript{3}OH process, BASF uses Catalyst ZnO and Cr\textsubscript{2}O\textsubscript{3} (70/30) at 320-380°C and 240-340 bars of pressure, while ICI uses CuO-ZnO-Al\textsubscript{2}O\textsubscript{3} at 230-270°C and 55-100 bars.

For Syngas production (by Russia, Westinghouse and Tektronix) copper electrodes for high voltage and high power (up to 1000 KW) are used for plasma arc production from mixtures such as CO\textsubscript{2}-H\textsubscript{2} created from the treatment of coal. The copper electrodes are required to be cooled for this treatment and point out that copper oxide Cu\textsubscript{2}O, which is a semiconductor, plays a key role in the energy transfer and the time life of these electrodes. It is expected this method will scale up to 500,000t/year in 2009.

For methanol synthesis the usual catalyst is Cu/ZnO/Al\textsubscript{2}O\textsubscript{3} and commercialization is under way for a methanol to olefins technology.

An integrated gasification combined cycle (IGCC) plant called GreenGen has been constructed in Tianjin, China. It was approved by the Chinese government in June 2009 and turns coal into gas which allows easy separation of CO\textsubscript{2} from combustible gases. This project is the leading carbon capture method for coal fired power.

The main advantages of plasma reactors processes are that they are high power processes from a few KW to 10 MW with a short residence time of a few seconds because of high kinetic rate. The process reactor is small (10 times smaller than a usual thermal process) and the high flexibility of such a process with a starting time of few minutes, is in agreement with the energy storage from NTE (new energy sources). The direct energy transfer from electrons to molecules results in high efficiency energy transfer.

Plasma gasification has been extensively studied by Ph. Rutberg (RAS), Saint Petersburg Electrotechnical Institut / State Polytechnical University of St Petersburg (Russia).
Electrochemical processes are used to produce hydrogen from water that can be used to reduce CO$_2$. \[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \quad (\Delta\text{H}=-165\text{Kcal/mol}) \]. In Japan (Hashimoto), electrocatalysis of sea water is performed with a Ti/Mn-Mo-SnO$_x$ anode and a Ni-Fe-C or Ca$_{18}$Ni$_{13.5}$Fe$_{3.4}$e cathode. Also under investigation is the catalysis for CO$_2$ reduction in fixed bed reactor using zirconium oxide stabilized by Sm (tetragonal structure) + Ni sites for the redox reaction (amorphous deposit of a few nanometers).

In the United States there is research going on to use photovoltaic energy and CO$_2$ for energy storage. The goal is to demonstrate the transformation of CO$_2$ to CH$_4$ from renewable energy in a pilot plant.

Amoureux and his colleagues are involved in the use of non-equilibrium plasmas with an electrocatalytic reactor to produce a specific electronic excitation without heat generation. This will open the way to the synthesis of chemical products by oxosynthesis. The excited states of carbene are under investigation.

Electrical sources of energy in combination with a supply of hydrogen can convert CO$_2$ into energy storage fuels like CH$_4$, CH$_3$OH, CO and SYNGAS. During the development phase of CO$_2$ capture at large scale, research has to be undertaken at the international level to develop new catalysts and the splitting of H$_2$O by solar energy, and to evaluate the economics of these processes.
Account must be taken of the fact that electric power supply must be optimized each day with population and industrial activities. Also the demand of electricity will increase by a factor of 2 from 2009 to 2050 and the nighttime cost of electricity is 20 times less than the daytime cost. The demand for electricity during rush hours must be factored in and note must be taken for the fact that in many countries large electrical power plants using coal and lignite are without CO\textsubscript{2} trapping.

These considerations have stimulated a strong R&D effort to find solutions to this problem. Carbon dioxide storage can be achieved by absorption with liquid such monoethanolamine (MEA) or NH\textsubscript{3} by adsorption by zeolites or carbonates at cryogenic temperatures. The carbon dioxide produced is a super critical liquid with high purity close to 99% and an efficiency of these processes close to 90%.

In 2015 the European Commission proposes to support 10 fossil fuel burning electrical of 1000 MW each for a total amount of €12 billion (a 1000 MW coal-fired power station 5 million tons of CO\textsubscript{2}/year). Industrial pilot plants for smaller capacities between 10 to 200 MW are working today (BASF, TOTAL, ALSTOM, Dow Chemical, IFP, RWE, BP, and Power Pass Corp) and new one are starting in China with Huaneng Group, the biggest electricity provider in China, and Shenhua Group the biggest coal producer in China. The conclusion is that liquid CO\textsubscript{2} can be produced at an industrial scale for a cost of 30$/ton.

Carbon can be recycled through REDOX processes just as metals are. Carbon dioxide is a good source for synfuels from CO + H\textsubscript{2} mixtures in catalytic plug reactors. Many patents and pilot plants are starting because these processes are close to financial balance if the cost of petroleum is between $80 and $100
The Fischer-Tropsch reaction (CO₂ + H₂ → oil) is being studied in the USA and South Africa. CH₃OH production (CO₂ + 3 H₂ → CH₃OH + H₂O) is under investigation in the USA, CHINA and EUROPE while CH₄ production (CO₂ + 4 H₂ → CH₄ + 2H₂O) is studied by BP and JAPAN. Syngas production (CO + H₂) from coal gasification with an arc plasma torch using CO₂ or a mixture CO₂ + H₂O at 5000°K is also being developed. These storage systems can reach a power of 100,000MW.

Network regulation will play a large role in the storage of energy derived from the reaction between CO₂ and H₂. Today these technical processes exist only at small pilot plants scale (CEA, AREVA, DOE, and BP) but they open a new strategy for the network regulation from nuclear plants and NTE development (the storage of thousand of megawatts).