MSE 395 DESIGN PROJECTS FOR SPRING 2014
(alphabetical order by advisor's last name)

1. **Materials for Sustainability (Prof. J. Abelson):** The Ashby eco-selection equations are combined with the CES/Granta database to calculate the energy consumption and CO2 footprint associated with the use of materials throughout the lifetime of a product -- from materials production through manufacturing, product use, and recycle or disposal. This group will learn the Ashby methodology and apply it to analyze the ecological and economic consequences of a proposed engineering approach such as "we can save gasoline by making cars lighter in weight; that is achieved by replacing steel components by fiber-reinforced composites." But is there a net energy savings? Reference: MF Ashby, Materials and the Environment: Eco-informed Materials Choice (Butterworth-Heinemann, 2009).

2. **Power packs for deep space travel (Prof. Averback)**: Space probes that travel much beyond Mars need more power than solar cells can provide. For example the voyager spacecraft that is now exiting the solar system carries no solar panels on board. Instead these vehicles use the heat (energy) generated by the radioactive decay of plutonium 238 to drive thermoelectric generators (radioisotope thermoelectric generators (RTG's)). But are RTG's the most efficient use of thermal energy (RTG's are 3-7% efficient) and do we want to launch hundreds of pounds of what Ralph Nadar called the mostly deadly element known to man. (Nader claimed that a pound of plutonium dust spread into the atmosphere would be enough to kill 8 billion people, but calculations show that one pound of plutonium could kill no more than 2 million people by inhalation – whew!). This project will consider such aspects as materials for packaging of the Plutonium (in case the launch explodes), efficient RTG's or possibly other methods such as Stirling engines.

3. **General thin film transfer approach (Dr. Geoff Brennecka, Sandia National Lab):** The Rogers group has done an excellent job of bringing the functionality of hard materials (mostly semiconductor-based) to flexible applications with low-cost substrates. Can we take cues from their work and that of others doing nano/micro/meso-scale transfer to integrated the functionality (and performance, efficiency) of continuous and/or patterned thin films? Let's focus on ceramics for simplicity and choose a material such as BaTiO3 (ferroelectric, high permittivity) and/or LiFePO4 or Li2TiO3 (battery materials). The ideal solution is one that uses scalable (ideally atmospheric, e.g., solution-based) fabrication which produces films with properties similar to the best reported but integrates those high-performing films onto flexible, low-cost (e.g., polymeric) substrates. One potential approach would be to deposit the films on a standard high-temperature-capable substrate (e.g., Si), perhaps with the help of a release layer, and then transfer those to a cheap and flexible substrate. Other possibilities are of course welcome--the keys are large-area capability, high performance, and cheap polymer substrates.

4. **Materials Design for Gene Delivery (Prof. J. J. Cheng):** The project is to design systems for efficient non-viral gene delivery. Gene delivery using polymer or lipid based vectors shows either low efficiency or high toxicity. The team is expected to integrate nanotechnology into gene delivery, and come up with a rationally designed system to address one or more of the critical issues in gene delivery: DNA stability, internalization efficiency of delivery vehicle, unpacking of DNA and trafficking of DNA to nuclei.

5. **Design of Anticancer Nanomedicine (Prof. J. J. Cheng):** The project is to design nanomedicine for efficient cancer targeting. Targeted delivery of anticancer agents to cancerous tissues can give improved efficacy and reduced toxicity. Cancer targeting using nanometer sized devices has been attempted for decades; but only limited success has been achieved. The team is expected to integrate nanotechnology into anticancer drug delivery, and come up with a rationally designed nanomedicine to address critical issues in anticancer drug delivery: nano-formulation, control over drug loading and release kinetics, internalization efficiency of nanomedicine, control of anticancer ligand surface density, in vitro and in vivo targeting efficiency and anticancer efficacy.

6. **Design of Trigger-Responsive, Polymeric Controlled Release Systems (Prof. J. J. Cheng):** The project is to design polymeric materials that can self-assemble to form nano- or micro-structures that can be used to encapsulate cargos. The cargos should be stably encapsulated for weeks or months. But once an external trigger (e.g., UV, enzyme, elevated temperature, water, pH, etc.) is applied, the encapsulated cargo can be very quickly released from the polymeric nano- or micro-structures. Such system can be tremendously useful in controlled release and drug delivery applications.

7. **Biocompatible batteries (Prof. S. Dillon):** A major challenge for electronics functioning within the body is the need for energy storage that has high energy density and is safe. Current technologies are primarily based on improved packaging for existing battery technologies, such as lithium ion, rather than the design of materials that are inherently safe. The goal of this project is to develop *new* alternative systems that are intrinsically safe within the body.

8. **Design of an extraterrestrial fuel cell on Saturn's moon Titan (Prof. Ferguson):** NASA's Cassini mission has provided evidence for the presence of liquid methane lakes and/or subterranean methane clathrates ("methane ice") on Saturn's largest moon, Titan. At 1.4bn km from the sun, the solar irradiance on Saturn's larger moon, Titan, is approximately 1% that on Earth. Solid oxide fuel cells (SOFC) offer a robust, long-term, and efficient alternative to solar electricity generation from light hydrocarbon feedstocks. In this project, the team will design an extraterrestrial SOFC station to be deployed on Titan to supply electrical power to terrestrial rovers and scientific equipment. The team will confront challenges associated with extremes of temperature, reduced gravity, a hostile atmosphere, and remote robotic delivery, installation and maintenance.

9. **Neovascularization of tissue engineering scaffolds (Prof. K. Kilian):** A major challenge in the design of materials for tissue engineering is neovascularization—the formation of blood vessels—to provide nutrients to cells within an engineered scaffold. In this project students will devise a method to fabricate discreet regions of vascular endothelial cells within a material to be cultured with tissue specific cells towards the design of a scaffold that promotes vascularization. The materials should be designed to promote vasculogenesis in distinct regions separate from the tissue cells. However, after fabrication the material should be amenable to degradation/modification for in vivo integration and angiogenesis (growth of new blood vessels).

10. **Geopolymers (Prof. W. M. Kriven):** Geopolymers are a class of inorganic, amorphous, rigid, gels that set at ambient temperatures into ceramic-like, materials that are thermally stable to ~ 1000°C when they crystallize into various ceramics. They are inorganic polymers which have a nanoparticulate and nanoporous microstructure which can be easily prepared by curing at room temperature. It is proposed to develop geopolymer composites containing second phases, which can act as toughening agents (chopped ceramic or metal fibers, spheres made from recycled waste glass) so as to reduce the brittleness for a possible application from a range of applications in advanced construction materials. Porous geopolymer materials could be investigated for filtration and CO2 sequestration. The project will involve selecting a particular application and making and evaluating the appropriate geopolymer composite.

11. **Design of a surgical mesh to improve tissue regeneration and healing of damaged tissue (Prof. Leal):** The team involved in this project will be confronted with the challenges in designing a material offering superior wound repair capabilities. This project aims to develop a surgical mesh that promotes quicker healing while providing a scaffold for tissue incorporation and growth. Potential applications include hernia repair, radiation injuries, and diabetic ulcers. The material design will involve the coating of regular surgical mesh with different kinds of biocompatible species such as lipid membranes and see how the modified mesh responds to increasing amounts of biological fluids.

12. **Design of a High-Efficiency Pyroelectric Energy Harvesting System (Prof. Lane Martin):** Each year we lose approximately 60% of all energy produced as waste heat. Recently researchers have focused on routes to harvest this waste heat for energy production and to increase overall energy production efficiencies. One such route is the use of thermoelectrics. Thermoelectric materials, however, have strict requirements in terms of electronic and thermal properties and must be able to maintain a large temperature gradient. Despite nearly 30 years of research, thermoelectrics remain unrealistic for everyday use. Alternative techniques for waste heat harvesting include a process called pyroelectric energy harvesting. As part of this program the students will design a pyroelectric energy harvesting system based ferroelectric materials. Such systems are solid state heat engines (i.e., no moving parts) that can harvest oscillating temperature profiles for energy production through the implementation of the appropriate thermodynamic cycles. The students will examine the competing materials requirements in selecting and optimizing materials for this application, will design a device and investigate the losses in this system, examine new thermodynamic cycles, and investigate pathways to enhance performance.

13. **Design of a Phase Diagram Experiment for MSE 307:** This design project will work with Angus Rockett and Nicole Robards to develop an improved set of materials to be studied in the MSE 307 undergraduate laboratory looking at phase equilibrium. The project will require design of the experiment and selection of appropriate materials that will improve optical contrast in the microscope-based laboratory and conducting that experiment and showing how it works relative to the existing approach. We will then use the DSC to study the same materials system to see if a phase diagram and heats of mixing/melting can be reasonably obtained in the DSC.

14. **Design of a photovoltaic power system for the MSE building (Prof. A. Rockett):** This project requires students to design a photovoltaic (solar cell) array for the MSE building. Students will create a realistic timeline for the project, determine the roof area and estimate the power output the system will provide, select a photovoltaic technology and estimate the cost of the system, and compare the levelized cost of electricity ($/kWh) with the cost that the University pays for power from the Abbot Power Plant on campus. If a system can be designed that is cost effective a proposal based on the design can be submitted to the Campus Sustainability Committee.

15. **Design of a Novel Backpack for Long Distance Hiking (Prof. A. Rockett):** This project challenges students to create a novel design for a backpack designed for long-distance hikes and expeditions. Traditional pack designs are typically based on a large polymer bag with straps attached. Can you come up with something better using advanced materials? If the participating students so desire they can construct their novel backpack design and test it outdoors as time permits. Teams should be three to four students.

16. **Materials design for skin mounted electronics. (Prof. J. Rogers):** Design of materials that provide reversible, non-invasive interfaces to the skin. Select and evaluate a variety of elastomeric polymers for use in reversibly delivering thin film electrodes to the skin. Correlate molecular structure, surface chemistry and mechanical properties to the robustness of skin adhesion and biocompatibility.

17. **Materials for arsenic removal from ground water (Prof. Jian-Ku Shang)**: The ground water in some central Illinois communities was recently found to contain high levels of arsenic. Arsenic is a class-I carcinogen and is known to cause a wide range of health problems. For safe drinking, the maximum arsenic level in water must be kept below 10 ppb. However, removing arsenic from water is complicated by the fact that arsenic may exist in both trivalent and pentavalent forms. While the pentavalent arsenic ion, which carries a negative charge in water, may be effectively removed by promoting its electrostatic interaction with an adsorbent, removal of the trivalent arsenic presents a great challenge because the trivalent ion has a neutral charge in water. In this project, we will examine new materials which may form a strong surface

complexion with the trivalent arsenic and use them to design and build a simple device to remove arsenic from the ground water in a central Illinois community.

18. **Alma Mater Material Design and Selection for Attachments (Dr. M. Sherburne):** Materials selection and design for the attachments of the Alma Mater to the base. One of the major issues that has come to light with the Alma Mater is the damage that has occurred over the years due to the use of iron-based attachments. An electrochemical potential is established due to the dissimilar materials and this has led to damage at the base of the statue. In this project you would be examining different materials that might be used as attachments. Would it be possible to design and process a Bronze metal with the required strength to serve as the attachment? The restoration engineer has suggested materials to be used as attachments would these materials be appropriate?

19. **Determine the Best Approach to Restoring Heavily Damaged Section of the Alma Mater (Dr. M. Sherburne):** Study the corrosion of the Alma Mater at joining and determine the best approaches to repair damaged sections of the statue. The Alma Mater is not a single monolithic piece of Bronze; it in fact has joints at which the different segments are joined. At these joints and due to the selection of joining materials, corrosion occurs in the interior of the statue. You would have sample from the statue to study and compare to industrial standards in order to determine the best approach to minimize the internal corrosion and ultimately repair these gaps in the Alma Mater.

20. **Quantum Dot Photovoltaics (Prof. M. Shim):** This project will survey current materials and device designs for QD solar cells, assess their competitiveness with current and/or near-future technologies and, if appropriate, propose means of improvement that will enable QD-based solar cells. Key questions to address include 1) what are the unique aspects of QD solar cells, 2) what are the main challenges with respect to materials choice, device fabrication, charge separation/extraction processes, overall efficiency & cost etc. 3) where is the most improvement needed?

21. **Quantum Dot Light Emitting Diodes (Dr. K. Deshpande, Dow Chemical Company/Prof. M. Shim):** QLEDs are an emerging class of devices that may have significant impact on display and solid state lighting technologies. QLEDs consist of colloidal quantum dots that combine high performance and power efficiency of inorganic crystalline semiconductors with the processability of polymers. However, there are several hurdles to overcome before QLEDs can be competitive with or surpass existing technologies. This project will examine materials' costs and availability; device design, processing and performance; and environmental impact in order to develop an improved or alternative QLED design that will enable these devices in display and lighting applications.

22. **Superconducting Magnetic Levitation Track Demo (Prof. D. Shoemaker)**

23. **Development of a Self-Healing Foam (Prof. N. Sottos) – please note, details of this project may change:** This project will involve surveying current polyurethane foam systems, identifying components that are suitable for microencapsulation, and developing a method to incorporate the capsules in a two-part commercial foam.

24. **Evaluation of flammability performance of thermal/acoustic insulation materials (Jenn Weber, Boeing):** You are a Material and Process Engineer in a Design Team that is responsible for designing an insulation system for the airplane for a variety of reasons (noise, thermal, flammability). This is a new airplane program. As part of a fuselage design team, you have been given the task to define the best material fit for the design requirements listed below. The desire is to research different polymers and validate (by test/analysis and/or research) materials that meet continued airworthiness requirements of flammability resistance as well as the other identified material characteristics defined by the design team. Selection of materials that retain their properties for the life of the aircraft is the optimum approach, but other factors

like weight, cost (material and manufacturing costs), and design concepts will be involved in final selections.

General Requirements of Thermal/Acoustic Insulation:

a. Must perform acoustical, thermal, and fire barrier functions.
b. Must not be heavy; New insulation material systems must not substantially exceed the weight of existing systems, which averages about 0.42 lb/ft3.
c. Must not cause or promote corrosion to the aluminum fuselage structure.
d. Must not be electrically conductive.
e. Must not interfere with inspection of the fuselage structure for corrosion, cracks, etc…
f. Must meet regulatory flammability, smoke and toxicity requirements.
g. Must not absorb large amounts of water.
h. Must not have adverse environmental and/or health/safety effects either during fabrication and installation, or in service use.

25. **Design of micro-heater for in-situ electron microscopy (Prof. Zuo):** The project is to design a high temperature micro-heater that can be employed inside a transmission electron microscope for in-situ study of phase transformation. Micro-heaters provide accurate temperature control at a targeted local area. They have broad applications, including sensors as well as microstructure characterization. Through this project, students will first review the current design of micro-heaters and propose own design and selection of materials for a micro-heater that is capable of heating up to 1200 C for an area of microns.