A Special Word of Thanks to Our Judges

It is my pleasure to offer a personal welcome to the judges of the Spring 2016 Colorado School of Mines College of Engineering and Computational Sciences Trade Fair. We appreciate your willingness to take time from your normal activities to evaluate our seniors’ capstone design projects. The opportunity for our students to get feedback from experienced engineers is invaluable.

Senior design allows our students to demonstrate the engineering knowledge that they have spent four or more years acquiring. We encourage you to spend time with the design teams and to inquire about their projects and their designs. But also ask about their design process, because in the final analysis, senior design is as much about learning the process of design as it is about creating a design. As these students enter the workforce, it is their ability to use the design thinking methods that they have learned that will serve them most in their careers.

We are proud of our students and their accomplishments and hope you are equally impressed. If you would like to get more involved in our program, we are always in search of more project sponsors. Let us know!

Again, thank you and Happy Judging!

Kevin L. Moore
Dean, College of Engineering & Computational Sciences
Colorado School of Mines thanks the individuals and families listed below who have provided valuable support to the Senior Design students presenting today.

**Program Partners**
J. Don Thorson

**Program Sponsors**
Gerald & Karen Zink

**Program Supporters**
Al Cohen Family

**Program Donors**
Steve & Jean Hamerslag
Colorado School of Mines thanks the companies and organizations listed below who have provided valuable support to the Senior Design students presenting today.

**Program Partners**
- Baker Hughes
- Shell Oil Company

**Program Sponsors**
- Chevron

**Program Supporters**
- Kiewit
- Lockheed Martin Space Systems
- Phillips 66

**Program Donors**
- Bechtel
- G-Force Motorsports
- IEEE
- Ricoh
- CVJ Axles*
- Metal Supermarket*
- Chevron Phillips
- Holcim Inc
- Newmont
- Syncroness Inc.
- EMJ Steel*
- N-Science*

*Indicates in-kind donations of material.
Sponsoring the Program

The Capstone Design Program relies on the generosity of our program sponsors to fund our intercollegiate competition teams, humanitarian engineering projects, and outfit the Senior Design Laboratory. If you, or your organization, are interested in supporting these elements of the program please consider making a financial gift through the Mines Foundation or via giving.mines.edu. Make sure to clearly mark your gift for the CECS Capstone Design Program. Your gift is tax deductible and will make a huge impact on our students.

<table>
<thead>
<tr>
<th>PROGRAM PARTNERS</th>
<th>Donate $25,000 or greater</th>
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<td>Your Funds support the needs of many teams. In addition, partners receive:</td>
<td>An invitation to the beginning-of-semester Project Kickoff event. All Sponsor, Supporter, and Donor benefits.</td>
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<th>PROGRAM SPONSORS</th>
<th>Donate $10,000 - $24,999</th>
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<tr>
<td>Your funds support the needs of multiple teams. In addition, sponsors receive:</td>
<td>An invitation to, and recognition at the end-of-semester Trade Fair event. All Supporter and Donor benefits.</td>
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<th>PROGRAM SUPPORTERS</th>
<th>Donate $5,000 - $9,999</th>
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<td>Your funds support the needs of a single team. In addition, supporters receive:</td>
<td>Recognition on the program’s website, and on signage in the Capstone Design Lab in the Brown Building Basement All Donor benefits.</td>
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<tr>
<th>PROGRAM DONORS</th>
<th>Donate up to $4,999</th>
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<tr>
<td>Donors receive:</td>
<td>Recognition in the end-of-semester Trade Fair Program and a formal letter of thanks from the Mines Foundation.</td>
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</table>
Colorado School of Mines thanks the individuals and organizations listed below who have served as clients for the student teams presenting today. Your donation of time, talent, and material support to our students is greatly appreciated.

Baker Hughes  
Chevron Philips Chemical  
City of Golden  
Clear Creek Watershed Foundation  
Colorado Department of Parks and Wildlife  
CSM Center for Space Resources  
CSM Civil & Environmental Engineering Department  
CSM Electrical Engineering and Computer Science Department  
CSM Mechanical Engineering Department  
CSM Metallurgical and Materials Engineering Department  
CSM Petroleum Engineering Department  
Denver Zoological Foundation  
Individuals  
Kiewit  
Lakota Outreach Housing Initiative  
Lockheed Martin Antarctic Support Contract  
Medtronic  
NEI Engineering  
Newmont  
POWER Engineers, Inc.  
Sanivation  
Shell  
VillageTech Solutions

John Macpherson  
Erik Lord  
Anne Beierle  
David Holm  
Sean Streich  
Angel Abbud-Madrid  
Dr. Shiling Pei  
Dr. Randy Haupt  
Prof. Jered Dean, Dr. Greg Jackson, Dr. Ventzi Karaivanov, Dr. Derrick Rodriguez, Dr. John Steele, Dr. Paulo Tabares, Dr. Xiaoli Zhang  
Dr. Jeffrey King, Dr. Terry Lowe  
Dr. Bill Eustes  
Paul Quick  
Paul Brayford, Lawrence Pearlman, Mary Page Smith, Chris Bottoms, Rob Hoefer, Ben Seling  
Paddy Douglas  
Tom Cilke  
Clifton Oertli  
Allison Coppel, Cynthia Parnow  
James Trumble  
Emily Woods  
Matt Sands  
Skip Stritter
Becoming a Client

The Capstone Design Program pushes students to go beyond their classroom training and solve real-world design problems. Every semester the college has over 50 student design teams who need great challenges to engage with. What opportunities does your organization have that could be addressed by a student team?

**SUGGESTED DONATION**

Corporate project sponsors are asked to provide a donation of $5,000 to the CSM Foundation. Up to $2,500 of that donation is made available to the student team for purchasing materials. The additional amount is used to support program facilities, staff and overhead. Government agencies, NGO's and startups may request exemption from the suggested donation but are generally expected to pay for project materials.

**TIME COMMITMENT**

The involvement of the project sponsor is a key factor in the success of the project. Great project sponsors will commit one individual for approximately 1 hour per week to support the student team. In addition, any training or on-site resources that you can make available to the students are greatly appreciated.

**OTHER**

Student access to construction sites, manufacturing partners, or other company resources is always appreciated by the students.

**PROFILE OF A GREAT PARTNER**

The most successful industry partners share the following traits:

- View sponsoring a project as an outreach activity which helps prepare their junior engineers for management.
- Choose projects from their “nice-to-have” list and avoid having students on their critical path.
- Treat students like an entry-level engineer and plan on providing guidance throughout the process.

**GETTING STARTED**

Check out our website at [http://capstone.mines.edu/](http://capstone.mines.edu/) for additional information on becoming a sponsor or send an email to design@mines.edu to start exploring opportunities with program staff.
General Information Regarding Trade Fair

JUDGE’S AGENDA

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<td>7:30 – 8:45</td>
<td>Breakfast Program</td>
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FINDING YOUR WAY AROUND

A floor plan and map of the Trade Fair is available on the back of this program for your convenience.

JUDGES LOUNGE

Snacks and beverages are available for judges in the Judges Lounge. Please feel free to take a break from talking with the teams and grab a beverage or snack in the lounge at any time.

GRADING

We seek to achieve consistency in grading between judges. With that in mind, the senior design faculty have developed the Trade Fair Ballot to aid your judging. Each row includes prompting descriptions that are intended to guide the evaluation process. Each description has an associated point value with it.

To completely grade a team, please select a single number from each row of the grading matrix. Sum the numbers (one from each row) and enter the total team score at the bottom of the ballot. Please return the form to the registration table when it is complete.
Spring 2016 Design Projects

Each year senior students in the civil, electrical, environmental, and mechanical engineering programs in the College of Engineering and Computational Sciences take a two-semester course sequence in engineering design targeted at enhancing their problem-solving and communication skills. Corporations, government agencies and other professional organizations, as well as individual clients, provide projects for the student teams to work on. Students spend the academic year developing solutions for the projects to which they have been assigned, using tools they have learned throughout their careers at Mines.

This semester, we are proud to present the work of forty-six design teams. Their collaborative design work culminates in today’s Senior Design Trade Fair. A list of the teams is provided below. In addition, each team has provided a one-page synopsis of their design challenge which is included in the following pages.

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* Did you notice the strange numbering for the “09” teams? These students were part of a special Human Centered Design Studio that was piloted for the first time this semester. The students worked as part of a mock design firm and may have worked on more than one of the projects being presented.
The National Concrete Canoe Competition (NCCC) is an annual event hosted by the American Society of Civil Engineers (ASCE). The purpose of the competition is to provide civil engineering students the opportunity to gain leadership, project management, and hands-on experience on a civil engineering related project. It is also intended to provide awareness of the benefits of obtaining ASCE membership, the durability and versatility of concrete, its technological and wide range of applications, which are essential to society, and ASCE’s commitment to civil engineering students.

This 2015-2016 academic year, Can-Do Canoe and their canoe, Stage Rock, represented the Colorado School of Mines in the Rocky Mountain Regional Concrete Canoe Competition hosted by Metropolitan State University of Denver and the University of Colorado at Denver from March 31st to April 2nd.

The proposed design for Stage Rock (Figure 1) used last year’s concrete mix and hull designs as a basis, in efforts to optimize the designs that had been effective in the past.

The theme was based on Red Rocks Amphitheater to represent the locality of the competition. The team used last year’s high strength concrete mixture with a unit weight less than water and incorporated a red pigment to accommodate for the restriction on the use of concrete stains. The hull was designed to obtain high stability, ease of turning and speed. To achieve these goals, a slight rocker (shown in Figure 2) was incorporated for high stability and the length was shortened from last year’s 18 ft to 16 ft, to ease turning without compromising speed.
Every year, the ASCE/AISC National Student Steel Bridge Competition (NSSBC) delivers a new proposal for the construction of a steel bridge that university students across the country compete in to design, erect, and load for the final competition. This year, the regional competition was held over the weekend of April 1st at the University of Denver. NSSBC asked for a bridge that could span at least nineteen and a half feet and have a maximum height and width of five feet. In addition to these dimensional criteria, the bridge must also span across a six-and-a-half-foot river. During construction, this river cannot be crossed (or touched) by any builder, tool, or component of the bridge.

At the competition, the bridge with the lowest total cost (or the lowest “bid”) is declared the winner. This final cost is based on the price given to each of the following categories (mirroring what could be expected in a real-world situation): weight, construction time, number of builders, violations, and aggregate deflection. Finally, all of these elements are added together to create the school’s final “bid proposal”.

Colorado School of Mines has participated in this event for several years, and, with the sponsorship from Kiewit, Blue Steel will represent the university again this year. The final design is shown below in Figure 1. As can be seen, the team chose an overhead arch truss with some decking support – similar to designs from previous years but with added detail to the connections. These connections were unique because every member of the bridge could connect to its respective member/s and stay there without the need for a bolt to hold it in place. Overall though, this design was decided because it had the smallest deflection of all the tested bridge types. Also, since deflection is the most heavily weighted in the final cost, the team decided to consider minimizing deflection over sacrificing the weight. As the SolidWorks model predicted, this bridge was around 200 pounds and deflected about an inch at each measured location.

Figure 1: Side View of Steel Bridge
As a part of the 2015-16 Drillbotics competition, our goal is to design and build a fully automated micro drilling rig. This competition is two phase. The first phase judges us on our rig design: safety, mobility of the rig, design considerations of possible drilling dysfunctions, the mechanical design functionality and versatility, and the control model algorithm. Our design submittal placed in the top 5 of the schools that participated. Only the top five teams proceed into phase two. In phase two we are judged on: construction quality, construction cost, performance, quality of wellbore (caliper, verticality, and tortuosity) and data handling and visualization. The team can only consist of a max of 5 people, has a budget of $10,000 and has various other competition limitations.

Some of the challenges on this project are that we are a small team and although we do have a graduate student in Petroleum Engineering on our team we have a limited amount of knowledge on drilling and automation control, so research and consulting with advisors on the project was critical. This project has been a huge learning opportunity. It is valuable to be able to actually design and build a machine that does what it should do, with a time limit and on a budget.

The official judging of the competition is scheduled to be on May 6th. We are the first Mines team to participate in this competition, and we want to thank all our donors and support on this project.

Figure 1 Solid Works Model of Rig Design
Team Blasterbotica was tasked with designing, testing, and building a rover to participate in the Seventh Annual NASA Robotic Mining Competition. In this competition, universities from across the country design robots to collect, transport, and deliver a minimum of 10 kilograms of simulated regolith within a 10-minute time period while traversing an arena containing several obstacles.

The design project has three main subsystems: drive train, excavation and autonomy/controls. The drive train system consists of four individually driven “salad-bowl” wheels in a skid-steer configuration. The excavation system has a bucket ladder that scoops regolith onto a conveyer belt and into a storage bucket. After driving back across the arena the bucket lifts and dumps the regolith into the final collection bin. The autonomy/controls system guides the robot to avoid obstacles, traverse the arena, excavate regolith, and dump collected regolith into the final collection bin. The rover starts in an autonomous mode but will switch to manual control if it encounters unexpected issues during competition.

The design process was driven by a rapid series of prototypes. Five iterations of in-sand testing and several simulations in the lab have refined our design to excel at competition.
The SAE (Society of Automotive Engineers) Baja Challenge is comprised of a 12-person Senior Design team in the Mechanical Engineering department of the Colorado School of Mines; our primary objective, to design, to build, and to race a vehicle in the Baja SAE Collegiate Design Competition consisting of 100 team on May 19th-22nd.

The competition consists of racing competitions to simulate real-world challenges facing engineers. The competition is separated into two categories, technical and dynamic. The technical events include a sales presentation as well as a technical design review. This portion of the competition tests contestant’s ability to support engineering solutions and push our skills to presentation and communication. The dynamic events put the contestant’s prototype through a grueling set of rigorous off-road events. These events include a hill climb, an acceleration test, a maneuverability event, suspension challenge and a four-hour endurance race.

As a team we are striving to finish top 10 in the overall competition this year. A top ten placement would establish Mines as a dominant automotive and design institution allowing future generations of students career opportunities in expanded fields of cutting edge automotive engineering.
The Mines’ Diesel Senior Design Team is a participant in the Shell Eco-Marathon Competition held in Detroit, Michigan in late April of 2016. This competition highlights the fuel efficiency of vehicles by measuring the fuel consumption of vehicles following ten laps, in 24 minutes, on a 0.6-mile track in downtown Detroit. Mines’ Diesel will be competing in the diesel class of the competition.

To accomplish the task of creating a vehicle capable of competing in the diesel class of the competition, the team has taken a design build approach with the goals of having the car weigh ~190lbs and have a MPG rating of ~1000 mpg. The team has completely designed the frame, steering system, body, drivetrain, and safety features. All of these components were designed using prior class knowledge, SolidWorks Simulation, and advice from professors and professionals with some initial performance calculations as a basis to how our design should be.

Fully assembled model of the frame with all components (left), fully assembled model with body design overlaid (center) and the team (right).

The Mines’ Diesel Team has utilized lightweight aluminum tubing (6061-T6) for the frame and carbon fiber for the body panels. A rack and pinion steering system has been used for the steering system. A custom manufactured steering wheel and front wheel support were made by the team. The team is currently in the process of testing the efficiency of the engine and making tuning adjustments to fully enhance our MPG potential prior to competition.
The Hyperloop is an idea proposed by Elon Musk as a next level transportation method that uses air bearings to levitate a pod travelling at high speeds through a low pressure tube. The concept relies on air bearings providing low-friction suspension and stability to glide a pod from one acceleration station to the next, maintaining speeds of up to 760 mph.

Team GLIDE competed in the SpaceX Hyperloop Competition. Our first step was to design a small-scale pod to race in the competition weekend. Of all the subsystems needed to make our pod successfully race down the track, ‘levitation’ has the lowest technology readiness level because of its reliance on unprecedented high speed air bearings. Team GLIDE is now delving into the fundamental questions behind air bearing technology, specifically using porous air bearings from Dr. Grover Coors and CoorsTek, in hopes to engineer a functional levitation design. We are now in our second round of testing in our development of high speed, porous air bearings. Our basic design is shown below:
In August 2014, Colorado School of Mines (CSM) started the CubeSat Senior Design Capstone project, MINESat, under the direction of the Antennas and Wireless Communications (AWC) Group in the Electrical Engineering and Computer Science (EECS) Department. The primary goal of the CSM CubeSat program is to design, develop, and launch a 3U CubeSat within a three-year program.

During the first year of the program, the inaugural team successfully developed and tested a proof-of-concept prototype for a 2U CubeSat. For the second year of the program, MINESat is developing and testing a fully-functional CubeSat bus with ground station that will meet NASA’s CubeSat Launch Initiative (CSLI) requirements. This bus will have several advanced features and space rated components, such as utilizing the Pumpkin CubeSat components Real-Time Operating System (RTOS), AX25 communication protocol, deployable antennas and solar panels. Furthermore, extensive studies will be conducted to determine the space missions that best correlate with the CSM missions of Earth, Energy, and Environment. The results of this second year efforts will be ascertained by a high altitude balloon communications test.
**Adaptive Skateboard**

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<tr>
<td><strong>Faculty Advisor:</strong></td>
<td>Dr. Joel Bach</td>
</tr>
<tr>
<td><strong>Consultants:</strong></td>
<td>NA</td>
</tr>
<tr>
<td><strong>Team Name:</strong></td>
<td>Adaptive Skateboard Team (AST)</td>
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<tr>
<td><strong>Team Members:</strong></td>
<td>Sydney Clark, Caleb Courkamp, Morgan Lindsey, Raul Tackie, Christian Whayne, Steven Wehr</td>
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Mr. Daniel Gale of the Adaptive Action Sports institute at Copper Mountain (ADACS) has contacted Dr. Joel Bach of the Colorado School of Mines in order to request the design and prototype of an adaptive skateboard handle for the disabled community. Members of the disabled community do not have an independent system to help them learn how to ride a skateboard. The goal of the improved adaptive skateboard handle is to allow members of the disabled community a means to learn how to ride a skateboard. As such, the target customer for this project is the disabled community, specifically those who can stand with little to no assistance. Coincidentally, the device designed will provide stability but is not intended to be entirely weight bearing. Furthermore, we hope that this project design will expand beyond the disabled community to the able-bodied beginner level riders as well.

The final design consists of the compression clamp, pivot joint, and clamp-lock shaft. The compression clamp will attach the entire design to the skateboard with enough force to counteract any force or torque the user inflicts on the handle. This results in a stable system minimizing the safety risk of using this device. The clamp consists of two clamps, or hook like objects, on either side of the board. The clamping height will be larger than the thickness of the board to account for the lateral curvature. Rubber shims will be used within the clamping height to ensure a snug fit.

![Figure - Final Handle Design](image-url)
Pressure ulcers are a constant danger for anyone in a wheelchair and with diminished lower body nervous function. The team has been tasked by Dr. Bach with proving the concept of active pressure modulation in partnership with Boa Technologies.

Current wheelchair seat pressure modulation systems are far from ideal in both effectiveness of pressure relief, stability, and in cost. These systems typically use air or another fluid in chambers to provide pressure relief to the user. The new design must meet a number of requirements, including effective, targeted pressure relief, effective instrumentation, and cost constraints.

There are many possible configurations for the seat, but common components include the surface, the matrix, the base, and the modulation. The modulation in this design must use Boa technology, and though there are an infinite number of ways to arrange the Boa cables, they are generally either horizontal or vertical. A vertical arrangement, shown below, enables direct pressure relief and has been selected for the project.

Instrumentation must effectively communicate, if necessary, the adjustment that must be made to the modulation system in order to relieve pressure. Thus, the system must be able to read an adequate resolution of pressure data points, process the data, and translate the data into the appropriate action, if necessary. Humidity, temperature, and shear are other specific channels which may need to be measured. The team has constructed a telemetry display which processes data from a pressure map on the seat and informs the user where adjustment must be applied. A prototype of the entire system has been created.
There is currently no viable technology on the market to aid visually impaired people in rock climbing. Although some have overcome many obstacles to become regular climbers, there is still a large barricade for the rest of the visually impaired community. A new system must bridge this gap between the desire to climb and the freedom to do so. We designed and implemented a system that allows blind climbers to be able to make use of their other senses in order to climb a climbing wall. Additionally, the system includes an element to allow for easier marking of speed climbing paths. The major priorities for the project were to make the new climbing wall easy to use for the climber and easy to install and affordable for the climbing gyms. Our goal was to minimize the amount of excess equipment the gym must purchase in order to implement our system. Our client is Chris Read at the Adaptive Sports Center. He gave us our basic design requirements and commissioned the project. Our customers are gyms looking for new clients as well as gyms looking to be more open to the disabled community. These gyms will be purchasing the finished product. The end user is the visually impaired, beginner to intermediate climbers that would like assistance climbing without having to rely on another person.

The final design consists of four separate subsystems: the hold locating, climber tracking, networking protocol, and hold design. Our final design for the hold locating methods implements a sound locating method. There are small holes in the hold so the sound from the speaker is able to propagate more freely. The climber tracking system is a wearable design consisting of magnets. The network design we used for our design is a mesh network built on the Zigbee protocol with a central device acting as the network coordinator. Each hold contains Zigbee compatible hardware configured as routers in the network hosted by the coordinator. The coordinator is a Raspberry Pi with a Zigbee compatible antenna. Additionally, the Raspberry Pi can connect to wi-fi so that a route design web app can be implemented in a future version of this project. Currently, we are using premanufactured holds with space for the internal components. Ideally, we would like to manufacture our own holds in the future.
Inertial Measurement Units for Biomechanical Analyses

Client(s): Joel Bach
Faculty Advisor: Joel Bach, Anton Filatov
Consultants: Amy Hegarty, Anne Silverman
Team Name: Freedom Motion Group
Team Members: Sarah Dunn, Maxwell Eshleman, Trey Hulbert, William Kelly

Biomechanical analysis offers valuable insight into athletic form, medical diagnosis, and the intricacies of human locomotion, but is often limited by traditional motion-capture laboratories. Current biomechanical analysis systems have high accuracy and effectiveness, but are extremely expensive. In addition, these systems are isolated to an immobile laboratory and are generally not representative of the typical environments for athletic or outdoor events.

Dr. Bach of the Mechanical Engineering department at Colorado School of Mines has tasked Freedom Motion Group with improving upon the standard means of biomechanical analysis by creating a system which may be used outside of a laboratory setting while maintaining kinematic accuracy. The system uses a series of inertial measurement units (IMUs) to determine the absolute orientation of various body segments (Figure 1). Currently, the system takes measurements on lower body extremities. The data from these sensors is sent to an onboard Raspberry Pi for data storage. From this, a musculoskeletal model is generated which allows the user to visualize joint angles and form during athletic events in order to gain insight into improving performance.

The system is located entirely on the user’s body and does not require any external wiring, which allows total freedom of mobility. Users of this motion system are able to perform any tasks which they desire and are able to do so in any environment, whether it is down a mountain or along a trail. Once the data has been collected, it is sent to an external computer which outputs the visual kinematic representation of the captured motion. The IMU motion capture system will prove useful to athletes attempting to improve their performance as well as researchers studying the biomechanical effects of various tasks outside of a laboratory setting.

Figure 1: Prototype IMU Motion Capture System
The Instrumented Ski Pole is a cross-country ski pole which measures the orientation and force exerted in order to provide objective feedback to an Olympic cross-country skier. The team was tasked by the client, Dr. Rodger Kram of the University of Colorado, Boulder, with designing and prototyping this ski pole as a tool for the Swedish Olympic cross-country ski team for improving performance as well as a research tool for biomechanical study.

Dr. Kram and his colleagues currently have a specialized treadmill and skis which make the skier stationary in addition to ski poles which can measure the force that the skier applies. This force is measured because cross-country skiers almost exclusively rely on their ski poles to propel themselves forward. Force data collected from the poles are used to determine the pace and performance of the skier.

The problem is that the Olympic ski team requires a device which can be taken onto the ski course which they train on. The current system is also unable to measure the orientation of the ski poles. The orientation of the pole is an incredibly useful piece of information for analysing the skier’s form. A skier who kneels low to the ground will feel a different result when he or she pushes off than one who is standing straight up even if they are pushing with the same strength. As a result, our team has developed the Instrumented Ski Pole. This is an everyday cross-country ski pole fitted with metal adapters which house a load cell between the handle and the shaft capable of measuring up to 250 pounds of axial force. Inside the handle are sensors which measure the velocity and acceleration of the pole in order to determine orientation. Raw data from these sensors are stored on any common micro-SD card, contained in a pack strapped to the arm of the skier, to be uploaded onto a computer for analysis. Future iterations of this design shall sport a more compact pack, a real-time display, and a telescopic shaft.
Monoski Binding

Client(s): Chris Devlin-Young
Faculty Advisor: Dr. Joel Bach
Consultants: Anton Filatov
Team Name: JAMAS
Team Members: Jeremy Meyers, Anna Corman, Monica Padeway, Andre Montes, and Sierra Richards

Due to a recent accident at a major competition Chris Devlin-Young, a world-famous Paralympic monoskier, challenged JAMAS to design a monoski binding system to increase safety and prevent release between the ski and the frame during alpine skiing events. This interface must allow the ski to flex naturally, not release at all once clipped in, and remain easily removable for transport, tuning and swapping skis. Ideally, this design must also have a change over time of around fifteen seconds, taking into consideration that another able-body person would be in assistance.

As a team, JAMAS analyzed the current binding design and brainstormed three different designs to meet client needs. These three design options have different ways of attempting to solve the client needs while maintaining the highest level of safety possible.

After several design iterations, the team decided on using a Twist and Lock Design. The twist and lock configuration eliminates the risk of detachment between the ski and the frame during use and has very high strength to weight characteristics. The pinned design within the twist and lock mechanism will allow for quick detachment when necessary, ease of use, and adherence to current low profile racing requirements. This design is the optimal choice based on our customer and client needs.
JAMS was challenged by Chris Read at Adaptive Sports Center in Crested Butte, CO to design a universal interface between the bucket (seat) and frame of a monoski. The critical deliverable for this interface is the minimization of change-out time between buckets. Additionally, though not required, fore and aft motion in the interface would be ideal to allow for adjustment of the skier’s center of mass over the system.

As a team, JAMS analyzed two different versions of frames – flat and angled – and brainstormed several options for the frame-to-bucket interface. The resulting design options had different ways of attempting to solve the client needs.

After several design iterations, the team decided on using the Binding-Style Locking Interface and Adjustable Wedge Design. By employing a dovetail clamping mechanism this design significantly reduces the change-out time and allows for fore & aft motion while maintaining system robustness and safety. The interface is completely universal as the pivot wedge, which utilizes existing mounting holes in the frame, removes any issue of connecting non-coplanar faces of the frame and bucket. This design is the optimal choice based on our customer and client needs.
Snowboarding Ankle Prosthetic

Client(s): Amy Purdy  
Faculty Advisor: Dr. Joel Bach  
Consultants: NA  
Team Name: PSAF  
Team Members: Sydney Clark, Trey Hulbert, Morgan Lindsey, Deanna Mitchell, Jonathan Tran, Christian Whayne

Adaptive Actions Sports at Copper Mountain (ADACS) contacted the Colorado School of Mines regarding a project consisting of designing a snowboarding ankle prosthetic that allows the disabled community to snowboard both recreationally and competitively. Currently, there is no commercial prosthetic design that is suitable for all aspects of boardercross snowboarding. Therefore, their desire is to make an ankle prosthetic that can function in all aspects of the sport and can provide stability to the rider.

Our design team pursued the slot machine design, which is a system based on a current prosthetic foot used by Amy Purdy with the addition of a machined slot to allow for the addition of plantarflexion. Similar to the commercial system, the slot machine design uses a spring in compression placed at the heel of the prosthetic (see figure).

With this spring placed in the rear of the prosthetic, the slot machine design has a static equilibrium position that will mimic a 90 degree angle between the foot and leg. However, when the prosthesis is in use, the slot will allow the lower pin of the shock to move along the prosthesis allowing the rider to enter plantar flexion. During carves in which the rider is engaging the toe-side of the board and engaging dorsiflexion, the lower pin of the shock will move to front end of the slot. In this position the shock will then allow compression into dorsiflexion and restorative force to return the rider to an upright position. Alternatively, when engaging the heel-side of the board the lower pin of the shock will move to the rear end of the slot allowing for plantar flexion and greater stability during the carve. Additionally, the increased degree of freedom provided by the plantarflexion action of this prosthetic will allow for better overall stability than the current designs when encountering rollers.
Team Prestige Worldwide was tasked with designing portions of a substation capable of receiving power from a solar array and stepping up its voltage to a transmission level of 345 kV. As the demand for sustainable energy increases around the world, the need for power distribution stations is very strong. This project required a mix of Civil and Electrical engineers to work together to design certain aspects of the substation.

The project began with reviewing the general arrangement and one line diagram of the project. From there, the Civil Team was able produce a site grading plan using Civil3D before moving on to design the Three-Phase Bus Support and Static Mast structures within the substation. Load calculations were prepared using ASCE 113 Design Manual and MathCad, then the structures were designed using SAG10, SAP2000, and LPile.

On the Electrical side of the project, the team developed the 3-line for the station, designed the ground grid for the site, and programmed the relays and developed schematics for the relays that help protect equipment in the substation. A protection and monitoring SCADA system was also designed by the Team. This system takes in data using Schweitzer Engineering Laboratories equipment to calculate and display data to utilize both autonomous and user operation of the substation.

Figure 2: Buffalo Dunes Substation - Steel Layout
Modular Shake Table Specimen

Client(s): Shiling Pei
Faculty Advisor: Angela Hager
Consultants: Andres Guerra
Team Name: Team Shake Plates
Team Members: Blake Beier, Drew Gillan, Nate Olinger, Stephen Sabo, Kirk Woltemade

Team Shake Plates was tasked with building an adjustable, collapsible, multi-story, single bay shake table specimen for the existing shake table located in the basement of Brown Hall at the Colorado School of Mines (CSM). The specimen will be used primarily as a visual aid for students enrolled in CSM’s EPICS, Intro to Seismic Design, and Structural Dynamics classes. The specimen will be stored in Brown Hall, and is designed for use by professors. The specimen must fail in a spectacular manner and be easily and quickly rebuildable.

We began with each team member creating a prototype idea then combining the best aspects of each design to create the ideal prototype. The specimen consists primarily of wood for the base and walls due to ease of constructability and low cost. Metal hinges were fabricated to secure the base to the walls and allow the structure to oscillate and collapse in one predicted direction. Thin wire is used as the breakable reinforcement due to the predictability of failure in tension. Our final design includes a one foot square bay and three, nine inch tall stories equipped with stoppers in order to increase durability of the design. The specimen is easily broken down into components for transportation, and can be fully assembled in under thirty minutes. The specimen will also weigh under fifty pounds total to ensure easy transportation.

Figure 1: Prototype picture and 3D CAD model of prototype
The legacy of artisanal small-scale mining (ASM) processes has had serious environmental and social consequences across the globe. Site reclamation requires a cohesive combination of intricate engineering methods, which address all the technical, social, and environmental complications. Duurzaam Development has conducted a scoping-level assessment for the reclamation of the White Sands Region (WSR); a part of Newmont’s Merian Mine concession in Suriname. This region is heavily disturbed by ASM operations from the last fifty years, leaving Tomulu Creek, which drains the watershed, with high total suspended solids (TSS) and turbidity.

ASM methods used in the WSR included dredging and water blasting of the streambed material and the use of mercury to separate gold from ore, resulting in disturbed banks, high turbidity levels, and mercury bioaccumulation in aquatic life. The goals Newmont and Duurzaam Development identified for the reclamation design include: restoring the ecosystem, reestablishing a natural stream flow, and enhancing Newmont’s social license to operate in the area.

In order to meet these objectives, Duurzaam Development has developed a final reclamation design, which utilizes riprap, sedimentation ponds, and active revegetation. These design elements will decrease the river’s flow rate and protect the banks from erosion to lower material loading in the surface water. Turbidity is expected to decrease, natural vegetation processes will come to dominate the site, and a natural river will be reestablished. A Participatory Local Procurement Plan has also been developed to maintain Newmont’s social license to operate by decrease tension between the community and Newmont. It is hoped that this project may serve as a model for similar ASM reclamation projects in the future.
Rainforest regions in Guyana, Suriname and French Guiana are all heavily impacted by Artisanal and Small-Scale Gold Mining (ASM). This project’s case study is in Suriname near the Merian Mine and represents one case within this global environmental challenge of managing ASM. This reclamation site contains exposed, eroding sediments which water transports downstream via river systems. Field samples from this site show high levels of iron, zinc, copper, aluminum, turbidity, and total suspended solids. Rural populations relying on water downstream are unaware this sediment transport may be causing community exposure to harmful compounds.

Reclamation design goals include reducing overall sediment loading, and therefore, the risks associated with mobilizing the metals present. Offsetting disturbance with increased biodiversity is a design requirement. Unique social challenges need to be addressed by this design because some local stakeholders would prefer to continue mining. Constraints include that the work proposed may be completed using the labor sources present in these ASM communities. Community training and labor opportunities both hope to strengthen Newmont’s social license to operate via local employment.

This design utilizes river flow restoration, site stabilization, sedimentation ponds, and revegetation techniques to implement site reclamation. Calculations of potential impacts due to changes in river flow have been evaluated with concern for erosion potential, and help define the criteria for this project. Plans for river bank stabilization, site recontouring, and utilizing vegetation aim to immobilize sediments while enhancing the site’s biological productivity. Site stability will not reduce the presence of metals, but will limit their mobilization downstream. Increased communication with local stakeholders and local labor procurement aims to increase community awareness of ASM’s related issues and foster local support for the project. After implementation on-site, sediment transport and its related issues are expected to decrease. Revegetation efforts will increase floral biodiversity, and create habitat for fauna; this meets the project’s biodiversity offset requirement. Water quality downstream will improve and protect community health, while also benefitting the environment. This work represents a potential model for reclamation of other ASM sites in the Amazon regions of the Guianas.
Many students at the Colorado School of Mines are required to take MEL II, a lab class that tests material and fluid properties using separate apparatuses. The fluid flow apparatus currently being used (shown in Figure 1) is difficult to operate and produces poor data, as the elevation pressure drop is so large that the frictional and minor losses are hardly detectible. Our goal is to improve students’ and faculties’ experience in the laboratory by creating an easier to use apparatus that collects data with comparable frictional, elevation and minor losses.

In order to create a design that meets all of the specifications detailed by the client, Team MIMI decided to recreate the MELII Fluid Flow apparatus with a different geometry and to redesign the testing deck (shown in Figure 2). The predominant change made was the inclusion of a rotating deck to facilitate both ease of storage and ease of use. When the deck is vertical, the storage footprint is greatly reduced, and when the deck is horizontal, the elevation change head loss is eliminated and the gauges are more accessible, both facilitating better data collection. Additionally, the new testing deck was designed such that all pressure data can be read by moving wires connected to transducers instead of reconnecting water filled pipes, as was the case with the old apparatus. This change will allow the user to switch between readings in a much more convenient manner. Lastly, all of the pipe diameters were reduced to increase the measureable frictional losses through all sections of pipe, and to reduce the amount of fluid (and weight) of the apparatus.

In order to quantitatively guarantee that the new apparatus will be able to function according to the client’s specifications, Team MIMI ran a number of pipe based fluid dynamics calculations to predict head losses, flow rates, and friction factors throughout the system. To ensure safety, Team MIMI also ran a series of moment based tipping calculations to ensure that the apparatus will be stable during normal operations and storage. With these calculations complete, Team MIMI is confident that our design will be able to run all of the MEL II experiments safely and efficiently.
Elm Hall Retrofit Challenge

Client(s): Dr. Paulo Cesar Tabares-Velasco
Faculty Advisor: Eric Bonnema
Consultants: Dr. Robert Braun
Team Name: Studio-15
Team Members: Steven Blickley, Brandon Gong, Sean Patrick McGinley, Joshua Mesward, Joshua Phillips, Steven Sandoval

The Elm Hall Retrofit Challenge sought to decrease the energy use of the Elm Residence Hall by 10% with a seven-year simple payback. By doing so, the project would not only decrease the annual utility costs for the Colorado School of Mines and increase the efficiency of the building’s systems, but would also reduce the environmental impacts of the building.

To meet this challenge, Studio-15 started by creating a three-dimensional energy model of the building using SketchUp and OpenStudio. From the construction documents, Studio-15 measured and compiled data for the three residence floors, the main office and lobby space, and the dining area. From here, direct discussions with the Department of Residence Life, Capital Planning & Construction, and Facilities Management gave Studio-15 the necessary information to model the day-to-day operation. The data was compiled from the Elm Hall building automation system, CSM historical energy data (via EnergyCap), and the Elm Hall as-built drawings. From here, EnergyPlus was used to simulate Elm Hall.

Studio-15 investigated how various energy conservation measures could affect typical building operations, energy consumption, and occupant interaction. After implementing these measures using OpenStudio, Studio-15 developed a retrofit package that could reduce the energy consumption of the residence hall.
Maple Hall Retrofit Challenge

Client(s): Dr. Paulo Tabares
Faculty Advisor: Eric Bonnema
Consultants: Dr. Neal Sullivan
Team Name: Maple Hall Retrofit Team
Team Members: Sarah Dewar, Emily Wong, Michael Harrison, Trevor Lager, Victoria Eagen, Isabel Goñi-McAteer

Purpose and Participants:
The purpose of this project is to create a building energy model to simulate a retrofit plan for the Maple Residence Hall on the CSM Campus. Objectives include validating the energy model using historical data, achieving a 10% energy cost reduction with a retrofit package, and remaining within a 7 year simple payback timeframe.

Dr. Paulo Tabares, Eric Bonnema, and Dr. Neal Sullivan’s expertise have been essential to the project’s success. Additional support provided by Mines Facilities Management and Residence Life has been extremely valuable.

Design Solution:
To complete this project, our team first performed a preliminary energy audit to gather general building information and utility data. Next, we created a baseline building energy model using SketchUp and OpenStudio. This process included inputting the following data:

- Internal lighting loads, occupant density, water flow rates, and plug loads
- Heating, ventilation, and air conditioning specifications
- Schedules that portray the daily usage of equipment, loads, and setpoints

Simultaneously, we investigated potential retrofit options and their corresponding OpenStudio implementation and calculated preliminary economic paybacks. Once the energy model was validated (within 10% of real utility consumption) we modeled the retrofit concepts. A final economic analysis ensured that the retrofit package met the payback requirements.

Importance and Stakeholders:
Creating a retrofit package has several benefits, including reducing negative environmental impact and contributing to a campus building energy reduction initiative. Stakeholders include the residents of Maple Hall, the campus community, and future senior design teams referencing our research.

Maple Hall Building Model
Building data was assigned to corresponding areas. Energy saving concepts were implemented after building model validation.
Mines abandoned in the 1940s, north of the town of Empire, Colorado have resulted in severe and on-going erosion of the natural slopes and streambeds causing water contamination and sedimentation of North Empire Creek. David Holm of the Clear Creek Watershed Foundation tasked Caesar Consulting with designing a drainage and erosion control plan for North Empire Creek. With the assistance of the client, Caesar Consulting was able to create a design involving streambed sediment removal, sedimentation ponds, drainage ditches and associated road crossings and revegetation in order to alleviate the erosion issues, minimize sediment deposition into the creek and improve water quality. A three-dimensional topographical model and a hydrologic model were created to determine storm flows that were used as design parameters for the drainage ditches and sedimentation ponds. The ditches are designed to handle a 50-year flood event and divert water away from the highly eroded areas. The ditches are also lined with riprap to prevent erosion. The final design addressed and mediated erosional and stream quality issues within the project boundary.
Newmont Mining Corporation is constructing the Merian gold mine in Suriname, South America that uses cyanide to extract gold. Nearby community members are concerned about the use of cyanide and its possible risk to the environment. Advanced Cyanide Solutions (ACS) was tasked with designing a cyanide degradation system to remove cyanide from the spent ore in the mining process, and to create a simple brochure that could be distributed to local community members for educational and reassurance purposes. The influent to the degradation plant is a slurry containing 35-45% solids and up to 60 ppm cyanide. The primary goal is to meet effluent standards of 0.5 ppm total cyanide and 2 ppm ammonia. To destroy the cyanide, ACS chose a chemical process that uses sulfur dioxide, copper and oxygen to oxidize cyanide to cyanate. This process produces acid and lime will be used to control pH. Cyanate produces ammonia in the presence of water. As result, a secondary treatment step using chlorination to oxidize ammonia is included in the design. The following diagram explains the core treatment process.

![Diagram 1: Primary cyanide degradation diagram including necessary equipment.](image-url)
POWER Engineers has tasked this team with developing a protection and control scheme for connecting a wind farm to the grid. The protection scheme must be reliable, dependable and secure. All pieces of equipment must be protected from electrical faults, especially the transformer. Additionally, faults in the system must be isolated to allow for continued operation of the unaffected areas of the system. To that end, the team provides a description of the protection design, short circuit study results, valid testing results, and a Supervisory Control and Data Acquisition (SCADA) system and communications package.

The wind farm in question is set up such that there is one primary transformer through which all the current generated by the wind turbines must pass. This transformer is then connected to the three feeders which lead to eighteen wind turbines on each feeder. The protection system for this project utilizes relays, circuit breakers, and fuses. Relays are used to identify problems in the system such as overcurrent, overvoltage, and undervoltage. This design uses relays to check for faults on either side of the transformer, and on each of the three feeders. In the event of a fault, the appropriate relay(s) will send a signal that opens the circuit breaker(s) closest to the fault. Each wind turbine on each feeder also has a fuse. The fuses protect the wind turbines and the rest of the system by melting if the current through the fuse is higher than the current that the fuse is rated for. When a fuse blows, its wind turbine is separated from the rest of the circuit.

In order to develop the relay settings, a power flow analysis and short circuit study were completed and checked with hand calculations. These studies helped students generate time current curves (TCCs), which are used to determine the final relay settings. These settings are then tested to confirm their validity on the relay rack. The SCADA design connects the seven available relays to one switch and then connects to HMI (Human Machine Interface) screens and the RTAC (Real Time Automatic Controller). The RTAC is used to gather the data and communicate it to the operators. HMI screens are used to display the data and also allow the operators to perform some basic functions for maintenance as well as alert the operators to any problems.

The project’s RTAC, relays, and Ethernet switch were generously donated by Schweitzer Electronics Laboratories, Inc..

A typical windfarm  
SEL 787 Relay Faceplate  
Example HMI Screen
The OreCart team was tasked with developing a moveable cart that serves as a station for an ABB IRB-120 robotic arm. The robotic arm is to be used in the mechanical engineering department's new industrial automation class. The cart design was later modified to allow attachment to an omni-directional autonomous platform to increase the functionality of the cart (not pictured below).

The cart houses the IRB-120 and its controller case. The cart is made of steel to increase the weight and stability. During operation, the cart has swinging outriggers to increase the cart's base area and eliminate tipping. Thanks go to our advisor, Mr. Young and our client, Dr. Steele, for offering their assistance and expertise during the project.
The goal of this project is to provide the CSM Nuclear Science Program with a storage system, testing stations, input/output ports, and a transference approval system that interface with an existing Pneumatic Transfer System. It is the continuation of the work of previous teams on the Online Nuclear Reactor Laboratory (ONRL) project.

Our storage system solution uses a linear actuator and carriage which holds 20 samples, and is able to keep track of the location of specific capsules. Its case is composed of T-slotted aluminum and steel L brackets, as depicted above. In designing this system, SolidWorks Simulation, as well as static and dynamic loading scenarios were considered in ensuring the actuator and case can withstand its daily stresses. The handshake system, constructed similarly to the storage system, is responsible for interfacing with the existing Pneumatic Transfer System, allowing transfers to be made between the two systems once approved by both CSM staff and USGS staff. The manual access port is machined from 4”x4”x6” solid aluminum blocks with an X cross-section at the end to stop the capsules. Attached to the X cross-section is a foam pad that helps stop the capsule and keep it from rupturing in the stopping process. A door allows for manual removal of the capsule for input/output purposes. Finally, the LabView-based control system is based off a National Instruments CompactRIO, an industry-standard embedded controller. A Windows laptop connected to the embedded controller provides a user interface for the transfer system.
Sonic detection and ranging (SODAR) is a type of instrument commonly used for wind profiling. The goal of this project involved working with Lockheed Martin to develop a mobile, rugged SODAR prototype that will support operations in Antarctica.

The objective of the SODAR Phase III team is to acquire, process, and analyze raw SODAR data in order to produce a detailed wind profile of the Amundsen-Scott South Pole Station. A dynamic wind profile of the area surrounding the research station will be used to predict areas of high snow drift accumulation; understanding these snow drifting patterns is a key factor in the United States Antarctic Program’s development of new research sites and facilities.

Three sonic beams, operating at different frequencies send audio signals and then measure these signal’s reflections to generate the data used in the wind profile creation. The SODAR prototype will operate in temperatures ranging from -10 to -50 °F. All wind profiles will be created with reference to the grid system used in Antarctic navigation.

The SODAR prototype developed meets the needs of Lockheed Martin utilizing three parabolic speaker/microphone combos. Acoustic enclosures surround each microphone dampening any background noise to the system. Electronics within the hardigg box generate, amplify, transmit, receive and record audio signals to and from the microphones. MATLAB software interprets the raw data and generates wind profiles.
Colorado Parks and Wildlife Duster Project

Client(s): Sean Streich  
Faculty Advisor: Paul Kaster  
Consultants: Dr. Greg Jackson  
Team Name: Doggie Dusters  
Team Members: Paul Foreman, Travis Clark, Chris Looney, Wyatt Olea, Brittany Sandoval, Matt Bennett

Plague is spreading through the prairie dog population of Colorado, but it is not the prairie dogs that are spreading it; it is the fleas upon their fur. Colorado Parks and Wildlife would like to save the prairie dog colonies from this plague. To do this, they have been spraying insecticide powder around the entrance to every prairie dog hole they can find. This ensures that any prairie dog entering or leaving those holes will coat its fur in powder, thereby killing the fleas.

The delivery devices used to spray the powder have shown themselves to be less than ideal. The following chart is a description of our solutions to the problems we investigated.

<table>
<thead>
<tr>
<th>The Problems</th>
<th>Our Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does not consistently deliver uniform amounts of powder</td>
<td>Actuating Measuring Cup systemSee figure</td>
</tr>
<tr>
<td>No measuring system to determine how much powder is distributed</td>
<td>Safety nozzle with powder escape routesSee Figure</td>
</tr>
<tr>
<td>No release valve for when they do clog</td>
<td></td>
</tr>
<tr>
<td>Device Clogs easily</td>
<td>Vibrating hopperSee figure</td>
</tr>
</tbody>
</table>

By building multiple prototypes, team Doggie Dusters was able to refine our design to its final form. Our final system measures specific amounts of powder, prevents clogging, will ensure the preservation of the Prairie dog colonies and will mitigate the problems Colorado Parks and Wildlife dealt with.

Our final design was made possible by our faculty advisor Paul Kaster, our client Sean Streich and our consultant Dr. Greg Jackson providing feedback and constant collaboration throughout our design process. A Special Thanks to Colorado Parks and Wildlife for the unique and rewarding project, as well as project funding.
Medtronic Off-Axis Micro Coil Winder

Client(s): Tom Cilke, Gregg Smith
Faculty Advisor: Dr. Yitz Finch
Consultants: Dr. Jenifer Blacklock
Team Name: Wonder Winders
Team Members: Deirdre Johnson, Leah Jaron, Tyrell Frame, Mitchell McCarty, Richard Garvey, Karen Burke

Medtronic is the largest stand-alone medical technology development company in the world. Among other things, they design equipment for minimally invasive surgeries to allow for accurate positioning in, for example, a patient’s brain. To achieve this, stylets with coils wound are used to interact with an electromagnetic field around the patient’s brain. The stylet location is calculated from this and then displayed on a screen with images of the patient’s target anatomy. The benefit of this method is that the surgeon does not have to rely on inaccurate methods of locating the surgical equipment. Further accuracy can be achieved if three coils of six layers each are wound at an angle, relative to the axis of the stylet with an offset of 120 degrees (Figure 1).

Medtronic has challenged the Wonder Winders to design a device to wind these off-axis coils using 56 gauge wire. This project serves as a proof of concept, and, as such, the team has opted to use 35 gauge wire as recommended by the clients as a starting point. The Wonder Winder’s solution to this challenge modifies an existing tesla coil winder design. The tesla coil winder involves keeping the wire applicator fixed in place while rotating and moving the stylet linearly to achieve perpendicular winds. The team’s design involves oscillating the wire applicator which will apply the wire at an angle. This design has been divided into six subsystems: linear actuation, stylet rotation, wire feeding, wire attachment, motor control, and user interface. The problem was approached incrementally and started by winding perpendicular coils with the tesla coil design. Once that was functional, the team implemented the off-axis winding system, adding more coils and layers after each step is successful.

Figure 1: Wire angle and positioning
Figure 2: Oscillation System
Imagine being able to take a picture from any distance, fly into a hostile environment without risk to human life, perform search and rescue missions in potentially dangerous areas, or survey land for construction purposes from the comfort and safety of your own home or office. Sounds great, but how is any of this actually possible?

Currently, all these tasks have been made possible through the use of an unmanned aerial flight vehicle called a quadrotor. Much like a helicopter, quadrotors use rotors (rotating blades) to achieve flight. However, unlike helicopters which only have two individual rotors, quadrotors have four rotors. These vehicles are extremely agile as the four rotor configuration solves several problems associated with vertical flight. The problem, however, is that quadrotors are unstable in windy conditions making the previously stated tasks impractical. For these reasons, Aerial Stability has been asked to solve the difficulties associated with outdoor quadrotor flight.

Specifically, Aerial Stability was asked to deliver both a working simulation of the quadrotor and to deliver a physical quadrotor capable of maintaining stable flight while in the wind.

To meet these requirements, a generic disturbance model was created to simulate any undesired movement of the quadrotor. In conjunction with this, data gathered from the on-board accelerometer as well as the GPS unit was used to determine when the quadrotor strayed from the desired position. Power was then allocated to the appropriate rotors to re-stabilize the vehicle. Our analysis stems from our simulation results, where we have optimized our control variables to ensure timely response.
The design task is to develop a testing machine that allows wheel and tire combinations to be tested to failure in a variety of real-world situations. These situations could include hard sustained cornering, large potholes, heavy acceleration and deceleration, combinations therein, and others. Testing must be conducted with the wheel and tire rolling at speed to maximize correlation to what they will see in actual use. The machine should be able to accommodate a very wide range of wheel and tires for commercially available automobiles, ranging from the subcompact market up through the large sports-utility market. As this machine will be used to test tens of thousands of wheel/tire combinations over its lifespan, it will need to be very durable to ensure that it can survive the loads imparted on the machine from testing.

The design solution is for this challenge involves several unique systems. The systems created consist of the drum, obstacles, support, suspension and power train. A large horizontally mounted drum with sufficient rigidity will simulate the road surfaces. The tire being tested will attach to a robotic arm that will simulate different suspension systems and turning motions. The drum incorporates pockets with obstruction inserts of varying depth to simulate potholes, curbs and washboard road conditions. The drum will be powered by a motor that will spin the wheel up to the desired speed of the test and can simulate acceleration, deceleration and constant speeds.

With the aid of faculty consultant, Anthony Petrella, and faculty advisor, Carolina Payares-Asprino, finite element analysis has been performed on the critical components of the system. Professor Robert Amaro contributed his knowledge of machine design and failure mechanics to assist iterative design processes in order to come up with feasible designs. We would like to thank Paul Brayford for the opportunity to work on such a complex and unique design project and for his advice and industrial expertise.

Figure 1: Overall Assembly
Chevron Phillips Chemical Company (CP) tasked our team to design a gas detection and isolation system for a salt dome storage facility. Natural gas is stored in an underground salt formation, where the gas volume in the salt dome is controlled by pumping brine in and out of the cavern. CP has had issues with natural gas entering the brine line when gas is being pumped into the salt dome. When natural gas is in the brine line, CP is forced to shut down the system and flare off the gas, which is both expensive and harmful to the environment. Gas flaring is the process of burning the excess gas in the line.

In order to develop a solution, flow characteristics were calculated to determine pressure drop and flow rates in the system. A change in pressure and flow rate can indicate there is gas in the line. The control system uses these calculations to determine when to isolate the brine line and minimize flaring. Local specifications require redundancy in the detection system in case one system is functioning incorrectly. Our redundant system is the flow meter detecting gas independent from our pressure sensors.

Our team, Gasbusters, has designed a solution that includes a weep hole, a flow meter, an isolation valve, pressure indicators, and temperature indicators. The weep hole is a small hole at the bottom of the brine piping used to minimize the amount of gas in the line, which will be detected by the sensors and isolated by the valve. The system is fully automated eliminating the need for manual operation.

Shown to the right is a layout of a typical salt dome. The *Hydrocarbon Product* represents the natural gas in our cavern. The pipe labeled *Brine or Water In or Out*, is where the isolation and detection systems are located. Gas enters the brine line when the brine level drops below the bottom of the piping. We are thoroughly excited to have had the opportunity to work on Chevron Phillips Chemical Salt Dome Challenge.
The project assigned to us by our client Baker Hughes was to design a rig heave measurement device or system that is completely independent of existing rig systems. Rig heave is defined as the vertical motion of the rotary kelly bushing (RKB) on an offshore drilling rig with respect to mean sea level, a fixed reference datum that the tides oscillate above and below. Our final design will accurately track the vertical motion of the RKB. The systems constraints as specified by our client are: a portable design, 5 mm precision, calibration mechanism, minimal external wiring, and a rugged weather-proof housing for all components. If possible our client requested a 30 day single charge operation life after set up with little to no maintenance.

To accomplish these constraints our team of six students has been assisted by our faculty advisor Dr. Yitz Finch and technical context consultant Dr. Ruichong Zhang. The approach that our team sees best fit to achieve the specified constraints of our client is through the use of multiple nine degree of freedom inertial measurement units (9DOF IMUs). 9DOF IMUs are comprised of three accelerometers, three gyroscopes and three magnetometers. In order to minimize error and get the desired precision our design uses high resolution 9DOF IMUs packed into a weather-proof housing and calibrated based on temperature as well as their relative distance from other sensors and the RKB.

The IMU accelerometers can be used to track the motion and instantaneous position of the IMU unit. Relating this position of the IMU unit to the RKB will be done by using triangulation based on the angle given by the gyroscope and the distance between the IMU unit and the RKB (a user input at the time of setup. Increasing the number if IMUs will give us redundant measurement and help us to recognize and reduce error. All IMU units will transmit their data via class one bluetooth to a computer that will have a program that has been written by us in order to track the position and motion of the RKB.

Figure 1: Four Arrangements of Inertial Measurement Units (IMU’s) and Accelerometers
Our team was tasked with developing a proof of concept for a system that can accurately and reliably measure the height, velocity, and acceleration of the traveling block on a drilling rig for Baker Hughes. The traveling block on a rig can be seen in yellow as #11 in Figure 1. Baker Hughes can then use this data to monitor the position and penetration rate of the drill bit in the formation to ensure a safe and efficient drilling procedure. It was also requested that the system can be easily attached/removed from the rig and can withstand severe weather conditions.

We chose to pursue a solution using video tracking analysis. This solution uses a grey scale line scan camera shown in Figure 1. The camera is autonomous from the rig structure in order to avoid errors caused by rig flexure and vibration. Easily removable LED strips will be attached to the traveling block upon setup to serve as markers on the block. The markers will be placed on the block a known distance apart to facilitate self-calibration.

The line scan camera then works in conjunction with Matlab software. We have developed code that is able to track the traveling block by finding the “bright” (LED) pixel values that are the correct distance apart in the image frame and then plotting these values. This shows the change in height of the traveling block. This data can then be used to find velocity and acceleration of the block using finite differentiation methods in Matlab.

In this way, our team has chosen a solution method that our client, FA, and technical consultant have never seen used in this context. We are happy with our project results and hope that our proof of concept can be expanded to full-scale application for Baker Hughes.
Our client is a certified Nurse Midwife with a vision for a more effective contraction monitor. The goal of this project was to turn a novel, patented concept of operation for contraction monitoring into a working product. The current sensor used by hospitals is a push button force sensor tocodynamometer and it is large, inaccurate, and lacks flexibility. Nurses must constantly adjust the monitor, and the sensors do not always work well due to their size and placement on the patient. The current tocodynamometers are also expensive, not always waterproof, and not very durable.

The first contraction monitor we designed follows the concept of the patent presented to us by Mary Page. Her patent consisted of a fluid filled tube immersed in a gel like material that would pick up pressure changes by a pressure transducer when a contraction would push against the flexible tubing. We took this initial idea and modified it slightly in order to lessen the diffusion of pressure through the gel like material. We coiled the tubing and immersed it in silicone gel. This design (pictured in Figure 1) is about four inches by four inches, flexible, relatively inexpensive, is compatible with current contraction monitor machines, waterproof, durable, and easy to use. When a contraction occurs, the tubing is pushed against making the fluid in the tubing disperse, causing a pressure difference that will be read from a pressure transducer. Our second design uses a flex sensor imbedded in a silicone gel (pictured in Figure 2). The Flex Sensor is compatible with the current contraction monitor, is flexible, inexpensive, waterproof, durable, and more accurate than the first design. Both designs would contain a flexible case in order to attach the tocodynamometer to a belting system that wraps around the patient.

Figure 1: Pressure Transducer Pad

Figure 2: Flex Sensor Prototype
Energy Absorption Hybrid Material

Client(s): Dr. Terry Lowe
Faculty Advisor: Dr. William Finch
Consultants: Mechanical Engineering Department
Team Name: Dancy Pants
Team Members: Michelle Preston, Michael Cothard, Brittany Holloway, Andrew Liebing, Marcelle Sprackling, Joshua Coors

Description

Traditional padding often relies on cellular foams to absorb energy. The drawback of this design is that the foam needs to be thick in order to be effective; resulting in a bulky pad that the target market, dancers, do not want to use. Dr. Terry Lowe and corporate partner Kadyluxe LLC won a Colorado State Advanced Industries Proof of Concept grant to create thinner padding that can compete with the current products on the market in energy absorption. This next generation of padding adds micro-structured “spring” lattices within the foam, to augment the momentum reduction properties, in conjunction with nanoparticle shear thickening fluid to form a Hybrid Material System that is significantly more efficient at protection than traditional padding. Our roles for aiding Dr. Lowe and his team include optimizing the lattice structures, and creating a machine to test the effectiveness of these new designs.

Analysis

In order to improve the lattice designs, our team is performing both FEA and physical tests using our impact machine. The testing machine is our custom design, tailored to be adjustable to accommodate for different test sample heights and impact energies. Dr. Amaro and Dr. Silverman have acted as consultants with regard to testing machine design and related calculations, while Dr. Finch, our faculty advisor, has assisted us throughout our project. Upon completion of our project, our team will provide Dr. Lowe with an optimized lattice design and an impact machine for future testing.
Denver Zoo Functional Automated
“WOW” Light Showpiece Challenge

Client(s): Paul Quick, Corri White
Faculty Advisor: Donna Bodeau
Consultants: Dr. Robert Amaro
Team Name: The Zoo Kroo
Team Members: Kyle Alexander, Gina Ogg, Jordan Daubenspeck, Garrett Hoffman, Brandon Smith, Rodney Roberts

Zoo Lights runs throughout the entire month of December and covers over 70 acres with millions of lights. With 150 animated animal sculptures, and many other events occurring throughout this time (such as ice sculpting), Zoo Lights is the most visited event for the Denver Zoo (Foundation). 2016 will be the first year that the Denver Zoo will be involved in the design, fabrication, and operation of new lighting sculptures throughout the zoo. The Zoo is looking for design and engineering assistance to come up with unique ideas and designs that can then move forward into build, test, and installation stages.

The Denver Zoo “WOW” Light Showpiece Challenge offered an opportunity for the Zoo Kroo to implement an interactive Zoo Lights experience available to all guests. Using vibration sensors on large playground drums, Zoo Lights guests will be able to control the light show by hitting the drums. The show will consist of an octopus being pursued by a shark. The octopus then escapes into a nearby coral reef and changes color to hide from the shark. The Zoo Kroo developed this idea to illustrate the mutualistic relationship between plants and animals through the tool of camouflage. The initial “chase” is set up on a rotational display that is speed controlled by the frequency of the drumming. After a certain number of drum beats the “show” will begin where the octopus escapes from the shark and camouflages itself in the coral. The display will then reset to the initial chase. Several lighting pieces will be connected directly to the drum beats and will turn on and off based on the drumming activity throughout the experience including the drums themselves.
The Looma, developed by VillageTech Solutions, is an educational device primarily intended for use in developing countries. It provides convenient, classroom access to the internet for village schools. There is one drawback, though—many developing countries lack a consistent source of power for the Looma. The challenge, then, is to design and fabricate a charge controller that is capable of conditioning power from the grid and a solar array to charge batteries that will power the Looma. In addition to handling high voltages and currents, the charge controller must account for the environmental conditions in Nepal, where the Looma is seeing the most use, while maximizing efficiency. By the end of the project, the client will receive a fully-functional prototype of the charge controller with supporting documentation.

The final solution centers around the DC2069A, a “high efficiency MPPT battery charge controller” from Linear Technology. It accepts 220-240 VAC from the grid and 200-400 W at 12 VDC or 24 VDC from a solar array. In the current configuration, the charge controller charges two 12 V, 120 Ahr deep-cycle SLA batteries. An Arduino Uno monitors the entire system, reading voltages and currents at the input and output of the DC2069A and temperature. If the voltage of the batteries falls below a certain threshold, the Arduino Uno disconnects any loads on the batteries. If the temperature rises above the operating range of the electronics, the Arduino Uno turns on a fan. The circuitry described above is protected by an enclosure made of ABS.

The engineering analysis is based heavily on datasheet specifications, with verification from calculations performed on equations provided by manufacturers. The enclosure was modeled in SolidWorks Simulation to check how it responded to static, impact, and thermal loading. For more information, visit us at Trade Fair.
Clear Creek Wildfire Sediment Control Challenge

Client(s): Anne Beierle, Deputy Director/Water Utilities for City of Golden
Faculty Advisor: Branden Gonzales
Consultants: Jeffrey Holley (CSM CEEN Department), Terri Hogue (CSM CEEN Department)
Team Name: Laminar Solutions
Team Members: Kara Davis, Melissa Mitton, Kathryn Newhart, Roderick Harger, Hannah Hebberd

Wildfire events can be detrimental to life and property, but the aftermath can have just as severe consequences to an even larger geographical area. Small amounts of water from rainfall post-wildfire will increase the risk of flooding and the rate of soil erosion. Sediment and debris loading to the Clear Creek watershed could be extremely detrimental to the water quality of Clear Creek, which is the main drinking water source for many municipalities. In general, water treatment plants that intake from Clear Creek could see a detrimental decline in quality of potable drinking water for the affected areas.

To solve this problem, Laminar Solutions has been tasked with minimizing impact of the sediments to the watershed. The scope of the project evolved to include a two-part approach. First is the design of a sediment basin and second is an emergency action plan.

Site Selection: Two sites were chosen and surveyed; see orange (Mill Creek) and pink (Chicago Creek) watershed areas in Figure 1. The areas were evaluated based on slope, vegetation, beetle kill, accessibility, wildfire risk, erosion potential and construction feasibility. These characteristics were chosen because they were linked to high wildfire and erosion risk.

Basin Design: Conceptual basin design was done for Chicago Creek. The sedimentation system collects sediment heavy water from flooding events and allows the particles to settle out before being reintroduced to Clear Creek. This will be done in order to minimize sediment overloading to water treatment plants.

Emergency Action Plan (EAP): The EAP is a flow diagram which provides instructions for the implementation of best management practices based on the terrain characteristics of a burn area. This document will impart guidance to organizations such as the forest service on how to proactively apply different BMPs to prevent sediments from entering into Chicago and Mill Creek as well as other water sources with similar terrain characteristics.
Team HOMES (Housing Outreach by Mines Engineers for Sustainability) is working in a partnership with the Lakota Outreach Housing Initiative (LOHI) to develop sustainable housing on the Pine Ridge Reservation in Oglala, South Dakota. Team HOMES is the third senior design team to work with LOHI to achieve their goal. While the two previous senior design teams worked to develop design plans for a house on the reservation, team HOMES has been tasked to design and build a quality-of-life monitoring system. This monitoring system, known as the EHL system (Environmental, Health, and Livability system), is designed to assess the livability conditions on the reservation. The system will be able to document improvements associated with the newly designed home. EHL monitors both social and environmental factors, then succinctly evaluates and outputs the data in an easy-to-read, user-friendly interface.

EHL measures environmental factors such as air quality, potential for black mold, and heating patterns. The system also monitors social factors based on survey data that is administered and collected by an ally of the reservation community (either a LOHI team member or another trusted person). EHL analyzes and displays the data through an internet interface designed by HOMES (Figure 1). The system EHL is designed for use within a home or in a series of homes on the Pine Ridge Reservation as decided by LOHI.

For this project, the goal of the EHL system is to analyze the impacts of engineering efforts on the reservation. While designing EHL, it was essential to consider cultural dimensions, sustainability, and incorporate humility into the design process. The quality-of-life monitoring system, EHL, has the potential to impact other efforts beyond the scope of this project. EHL is important and groundbreaking for it is a system that quantifies the success of a humanitarian project. Team HOMES has succeeded in developing a product that can help future housing projects. Millions of humanitarian efforts are made each year but there is rarely any type of follow-up to ensure the project has achieved its goal. EHL is unique for it outputs quantifiable data allowing the user to determine if their housing project was successful.
Sanivation, a nonprofit based in Naivasha, Kenya, challenged team Urine Good Hands with the task of converting a urine waste stream into a product that can be sold for a profit. The design solution must be scalable with Sanivation’s growth plan. Because urine contains high concentrations of nitrogen and phosphorus, the chosen solution was to precipitate the mineral struvite (MgNH₄PO₄·6H₂O) by adding magnesium. The struvite can then be separated from the urine, dried and sold as fertilizer to the large agricultural and horticultural industry surrounding Naivasha. The sale of struvite will more than cover associated production costs.

Design Specifics: Nitrogen is originally present in urine as urea, but through bacterially catalyzed hydrolysis is converted to ammonia.

\[(\text{NH}_2)_2\text{CO} + \text{H}_2\text{O}^{\text{urease}} \rightarrow \text{NH}_3 + \text{H}_2\text{NCOOH} \rightarrow 2\text{NH}_3_{(\text{aq})} + \text{CO}_2_{(\text{aq})} \] (1)

Struvite precipitates when the molar concentrations of magnesium, ammonium, and phosphate exceed the solubility of the following reaction, which is accomplished by adding magnesium.

\[\text{Mg}^{2+} + \text{NH}_4^+ + \text{PO}_4^{3-} + 6\text{H}_2\text{O} \rightarrow \text{MgNH}_3\text{PO}_4\cdot6\text{H}_2\text{O} \] (2)

The struvite yield from urine was optimized by determining the appropriate pH, reaction time and magnesium addition through the use of a chemical equilibrium model (Visual MINTEQ) and a series of laboratory experiments. A final experiment was performed to compare the fertilizing capabilities of urine-produced struvite with chemical grade fertilizers.

A reaction vessel was designed based on experimental parameters. This design will be implemented as a physical prototype in Naivasha, Kenya to provide a basis for future scaling up endeavors.
The wind tunnel design challenge offered our team the opportunity to create a large scale wind tunnel that will be widely used at the Colorado School of Mines across multiple fields of study: such as fluid dynamics, heat transfer, and machine design. With this project our team was tasked with creating an easy-to-use wind tunnel that could accommodate large items within its test section while still maintaining a consistent, uniform flow field. Our analysis primarily centered around two key areas: fluid dynamics and structural integrity. In order to ensure uniform flow over an object being tested we performed fluid dynamics simulations and developed computational modeling algorithms that helped to optimize the overall shape of the wind tunnel. This analysis was coupled with structural simulations that ensured our design would be able to withstand worst-case scenario loading conditions. In order to operate the wind tunnel our team integrated sensing capabilities which allowed for control and interaction via a LabVIEW program that provides users a simple graphical interface to operate the tunnel. This wind tunnel and all of its components would not have been possible without the help of our client, consultants, and advisors listed above. A few quick facts are presented below.

- Test Section Size: 3’ x 3’ x 4’
- Max Speed: 60 mph
- Sensing: 6 axis force/torque
- Contraction Ratio: 7.1:1
- Overall Length: 25’
- Power Required: 25 HP
Anti-Poaching

Client(s): Lawrence Pearlman
Faculty Advisor: Dave Young
Consultants: Dr. Vibhuti Dave
Team Name: Anti-Poaching Collective
Team Members: Marty Andrie, Franco Arbiza, Brendon Gesior, James Maroney, Kylen McClintock, Chris Rice, Frederick Rodgers

Our team has developed an inexpensive means of deterring megafauna such as elephants and lions away from villages in Africa. This reduces the number of harmful encounters between humans and animals which will ultimately decrease poaching and unnecessary deaths in the undeveloped world. Our solution to this problem is a device which harnesses solar energy to flash a bright LED at large animals when they get too close to a village or farm. The idea behind this flash design came from our client, Lawrence Pearlman, who spent time in Africa as a bush pilot. He noticed that when subjected to bright light at night, such as a camera flash, elephants tended to stay away to protect their night vision. Our device acts as a motion sensored flash to ruin the megafauna’s night vision and keep them away from farms and villages.

Due to patent issues, our project has changed to a research and design project for an anti-poaching device. We have designed a robust device, which costs a little more money than our original design budget, that we have performed extensive testing on to make sure that a device like this will function properly in Africa.

The device consists of multiple components to accomplish this task. A solar panel mounted on the top of the case will capture solar energy and charge the battery during the day. During the night, the solar panel stops charging the battery and the pulse infrared (PIR) motion sensor is activated. When the PIR motion sensor detects a large animal, it will activate the LED and direct a bright flash towards the animal. These parts are implemented in an acrylic case that is capable of mounting to a variety of objects using a Velcro strap and waterproofed using a rubber sealant.
Individual Broader Impacts Essay

This semester all Senior Design students were assigned to write and submit an individual essay about how their engineering choices impact the social, environmental, and/or economic lives of communities and individuals. The topic for this semester’s essay is:

Every day, engineers choose how and with what materials a challenge should be addressed. Whether it is the choice between wood or concrete structures, in situ versus excavation based approaches in remediation, or additive versus subtractive manufacturing engineers are making decisions that have long-term consequences. Present a discussion, using a contemporary, concrete example, of how engineering design choices to use specific materials or processes can positively or negatively impact society, the environmental, and/or the economy. The essay should be either related to your project or your field of engineering.

The top 10 essays from this group of approximately 300 senior engineering students were chosen by the course faculty and are included in this packet for your review.

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The top three essays have been judged by a panel of volunteer judges and winners of the best essay contest will be announced along with the Trade Fair results. This year’s judges were:

John Agee          Travis Brown       Robert Bruzgo
Robin Bullock      Paul Chamberlin    Brenda Chergo
Dick Collins        Paul Dorr         D.V. Griffiths
Stephen Kutska     Art Pansze        Anthony Petrella
Eric Phannenstiel  Kim Vilien        

We thank you very much for your time and effort involved in choosing the top essays!
A Sustainable River Waya

Audra Agajanian

As a little girl walks two miles with her five-gallon water bucket gracefully balanced on her head, a motorbike speeds by with four jugs precariously attached to it creating a cloud of dust and exhaust. It is early morning in the village of Waya and this is the first of two trips that will be made today to and from the River Waya. School will be starting, and students will be trickling in as they finish their morning duties. Heads will be nodding in exhaustion during lecture and generations of little girls will be dropping out of primary school to make time for their ever increasing household chores.

There are many engineering design options that would help this specific village in the short term, however, the design chosen would impact more than just the village. If the designer does not look outside the village and to the ecosystem as a whole it is probable that the design will not be sustainable into even the near future. More damage than good may occur.

Adaklu Water Project is an organization dedicated to bringing access to potable water to these children in Waya and to assist the local economy by boosting the agricultural productivity [1]. The organization has been considering a design that entails small scale damming of the River Waya. This design is centered on Waya; their households and their farming. The plan would restrict the flow of the river allowing for storage and possibly treatment before it continues downstream.

Downstream about 35 miles from the village of Waya, along the River Waya, is the Avu Lagoon. In the Avu Lagoon was found the Sitatunga, an aquatic antelope species that was considered extinct in this section of West Africa [2]. Conservation efforts have been underway to provide protection for these creatures and for their boggy ecosystem. The area around the lagoon has come to benefit from the ecosystem services the Avu Lagoon provides. These services include emerging tourism businesses and natural filtration of the water. Between Waya and the Avu Lagoon also lie three other villages. These villages rely on the River Waya for sustenance farming and household water needs. With knowledge of these downstream stakeholders, Adaklu Water Project needs to be able to provide accessible water to the children of Waya and maintain the flow downstream.

This is, indeed, a difficult task and one that cannot be taken lightly. The damming project will not allow for preserving the current level of downstream flow to the lower villages or for the Avu Lagoon. The consequences that damming the River Waya could have on the delicate ecosystem of a coastal lagoon may be irreversible. The volume of the Avu Lagoon would decrease due to restricted inflow from
upstream. This would subtract from critical habitat and from the water supply enjoyed by the living beings in its vicinity [3]. Restricting the flow from upstream would also deprive the villages along the path of the River Waya and could have negative consequences to their farming and household water supply.

Adaklu Water Project thoroughly believes in preventing such unintended consequences during the design process. As the engineers contemplate specific design choices to keep their impact on the local society positive, they struggle with putting value on specific advantages and risks for each design. The designs will have to go hand in hand with education and training for the local population and will have to be passive systems requiring little upkeep and maintenance.

The suggested alternative design would include a series of small reservoirs running along village of Waya and or the agricultural areas. Drainage systems would be put in place, such as unlined open drainage channels, to feed into the reservoirs. The channels would be unlined as to not hinder the infiltration into the water table. They would be open to allow for ease of access for maintenance and also to ensure mosquitoes can be kept under control [4]. Research would be done regarding the amount of flow needed in the River Waya during peak flows of the rainy season. Consistent monitoring of the River Waya would ensure the necessary flowrates are maintained for the initial seasons of the project. This would show that the design is not over collecting water destined for the River Waya. The water in these reservoirs can then be diverted for agriculture or possibly treated insitu for village use.

While Adaklu Water Project's most visible goal is giving that little girl more time in the morning to attend her primary school classes without fear of tardiness or illness from her water glass, the simplicity of the solution is taken away by the realities of living in a world with limited resources and increasing knowledge of the potential unintended consequences that exist. This design would strive to preserve the health of the entire ecosystem that surrounds the River Waya and provide a water storage method for village of Waya. With the River Waya intact and the access to water increased, the benefits can have a longevity and consistency that is much needed for sustainable development.
References:


Little Decisions, Big Impacts

Caleb Clough

Often times, engineers do not realize that the simple choices they make in their designs can have broad impacts in many different aspects of life. Whether it be increasing the factor of safety for a given part, choosing between luxurious or economic options, or anything else, any choice an engineer makes will produce important and often unexpected consequences on society, the economy, and the environment. Even something as simple as changing the metal of truck body components can make a huge difference in the impacts of a product—a lesson that Ford Motor Company has learned with their F-150 truck.

For many years, the Ford F-150 has been associated with strength, durability, and dependability. This successful formula has earned the model the title of best-selling pickup in America for the past 38 years [1], and allows it to generate an estimated 90% of Ford Motor Company’s profits [2]. With its heavy steel frame and enormous V8 engine, the F-150 has begun to face challenges in the past decade, however. Specifically, the fuel economy standards passed by the Obama administration now dictate that the average fuel economy for all new cars and light-duty trucks sold by a given automaker must be 54.5 mpg by the year 2025 [3]. This daunting number is making it increasingly difficult for automakers to be able to sell the large SUVs and trucks many Americans desire. An example of such a vehicle, the most efficient model of the 2014 F-150 managed only 18 mpg combined fuel economy [4]. In order to overcome these abysmal numbers, Ford needed to rethink the pickup. To do so, they came up with a simple, yet elegant solution: for the 2015 model of the F-150, Ford replaced all of the steel body components of the truck with similar components made of a lightweight aluminum alloy. While perhaps simply a ploy to comply with federal law, this simple change of material by the engineers at Ford has ended up having profound effects on the environment and the culture surrounding their trucks.

From a technical standpoint, swapping the metals was an obvious solution to increase fuel economy. Steel is roughly three times as dense as aluminum (for similar strengths), so aluminum parts end up being much lighter than comparable steel parts. In the case of the 2015 F-150, the truck lost over 700 lbs without shrinking significantly in any dimension from the 2014 model [5]. In conjunction with a new, turbocharged V-6 engine, this change increased the combined fuel economy of the 2015 F-150 a staggering 22% to 22 mpg [6]. Given the volume of F-150s that are sold and subsequently driven each year, this 22% increase is not trivial. Greater fuel economy means less gasoline is consumed, which in turn helps to reduce the carbon emissions of the transportation sector. Many scientists agree that climate
change is one of most daunting obstacles that humanity currently faces, so any possible route to decrease society’s carbon footprint is extremely important. Even a small change in material, as is the case in Ford’s F-150 decision, can have huge impacts on the environment.

The environment was not the only area affected by the change to aluminum, however. As mentioned previously, the F-150 has a loyal following because it is viewed as an extremely tough truck. One can then imagine the concerns that were raised by F-150 aficionados when the company announced the truck would be built with the same metal that makes up flimsy cans and shredable aluminum foil. While the engineering decision was relatively straight-forward, Ford faced a much tougher public relations challenge from their simple choice. In order to convince the public that the new trucks were just as capable as their steel ancestors, Ford began referring to the truck as being made out of “high-strength, military-grade, aluminum alloy” and began touting the trucks’ increased payload and towing capabilities. Although many articles were published doubting whether or not Ford could maintain the culture surrounding the F-150, the sales figures for the 2015 F-150 show that Ford has indeed accomplished its goal of maintaining the public’s confidence. The fact that simply changing a metal required this much thought and discussion, however, highlights the fact that seemingly simple engineering decisions have broad societal implications as well—yet another facet that is not often considered by engineers.

Engineering is erroneously assumed by many to be a discipline that is clear-cut, linear, and formulaic. This belief couldn’t be further from the truth, however, and the Ford F-150’s transition from a steel body to an aluminum body is a perfect example of this. A seemingly simple decision, this change had profound environmental and cultural impacts upon implementation. These types of impacts are the exact reason why an engineer must consider the broader ramifications of his or her decisions in order to truly be acting effectively and ethically.
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Building the Bridge of Tomorrow

Jordan Hasz

Every day engineers are faced with decisions that will in one way or another impact society and the economy. Furthermore, there is often times pressure from stakeholders to favor one category over the other. For instance, an engineer could be tasked with designing a bridge to a specific budget limiting available resources and ultimately jeopardizing safety. On the other hand, a bridge project with a focus on green construction methods could choose to use wood over steel though the latter has a clear edge in overall strength. In any situation it is important to find the point where economic feasibility and safety meet, ultimately resulting in a sustainable engineering design taking into account not only current conditions but also the needs of future generations. This essay will attempt to narrow in on this meeting point as it pertains to bridge design in particular, along with good engineering practice in general.

Let’s begin the discussion by looking at a specific bridge design case from the late 1800s. The County Council in Inverness Scotland was calling for the design of a bridge to span 130 feet and carry a distributed load of 40 tons across the total span of the bridge. They took bids from multiple firms and chose to go with the most economic option. The lowest offer of $6,450 was accepted compared to the next competitive offer of $12,150 [1]. The bridge was built with steel, and the compression members in particular were designed to be able to withstand compressive forces of up to 143 tons in an ideal situation. The total combined loads were calculated to generate compressive forces of only about 104 tons – nearly 40 below the maximum load [1]. At a price much lower than competition, the County Council was delighted to implement the design. However the bridge never reached completion; the compression members buckled as the bridge was still in the final stages of construction (luckily no one was injured). Engineering News, published just after failure, described the provision against buckling as “totally inadequate and absurd” and attributed the failure to lack of sufficient bracing which would have reduced the total load on the compression members (though this would have resulted in a more expensive project). It should be noted that typical factors of safety for structural steelwork in bridges nowadays are between 5 – 7 compared to a mere 1.375 in the case described above [2].

Fast-forward nearly 200 years to a more well-known bridge failure. Minnesota’s I-35W bridge was designed in 1964 during a time when transportation in the United States was at an all-time high and, as a means of saving on cost, it was a common practice to build “fracture-critical” bridges. This means that failure of any of the bridges structural members would result in a total collapse. This was common practice
until the 1980s when the American Association of State Highway and Transportation Officials (AASHTO) implemented new specifications that required loads to be distributed to other supports in case of failure. Furthermore, because most large-scale transportation was still moved by rail at the time of construction, the bridge was built to carry only about 60,000 cars per day [3]. As the transportation industry evolved in the early 2000s the amount of cars that traveled on I-35W nearly tripled to 160,000 per day. The 40 year old bridge was beginning to deteriorate due to the increased load, and this came to the attention of Minnesota’s Department of Transportation (MnDOT). However MnDOT was reluctant to retrofit the bridge due to lack of funding despite suggestions from URS Corporation’s evaluation of the bridge in 2004. An investment strategy meeting was finally held in 2006 with a plan to re-deck the bridge no later than 2022. Unfortunately, the bridge collapsed August 1, 2007 resulting in 13 deaths and 145 total injuries ultimately costing $278 million for a new bridge design [3]. Barry LePater, writer of Too Big to Fall: America’s Failing Infrastructures and the Way Forward states in his book “The story of the I-35W is not an isolated tale of one state’s transportation agency. It is an apocryphal tale of a pervasive culture of neglect that permeates our national transportation system” [3].

These examples of cutting corners in order to save money are unfortunately only a few of many in modern engineering. Cost reduction is an inevitable component of engineering design, however, it is important that this does not jeopardize public safety. Although the first bridge example never made it past the construction phase, the second stood for over 40 years before failing. Neither however were examples of sustainable engineering design because they failed to take into account the full lifecycle of the bridge. When completing a project it is important to meet initial requirements, but in order to be sustainable, one must consider future events also. If the I-35W bridge had been initially designed with a plan for expansion, perhaps renovation would not have been delayed until it was far too late. This is good engineering practice for any application but especially in a growing transportation industry where it seems traffic is constantly increasing with roadways and bridges struggling to keep up. As traffic infrastructure is updated to accommodate the transportation of today it is crucial that the possible necessities of future generations are not ignored. Looking past minimum requirements to meet the needs of future generations is the only way true sustainable engineering design can be achieved.
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The Necessity of Space Travel with In-Situ Resource Utilization

Alexis Humann

Our Earth provides us with everything we need to survive. Earth’s atmosphere furnishes oxygen for us to breathe, carbon dioxide to trap solar radiation to keep us warm and nitrogen to supply nutrients to our soil. We have massive stores of energy resources, ranging from carbon-based fossil fuels, to solar and wind power. We have abundant fresh water and plant and animal based food sources. For humankind, and all other life here, Earth is literally a haven. While our planet is truly one of a kind, its resources are limited. Already, humans have begun to exhaust the finite resources available to us on this planet. Many other planets exist which are capable of sustaining life, however, we do not currently have the technology necessary to enable space travel and colonization. For humankind to survive on any other celestial body, we will need to either bring all of our necessary resources for survival or we will need to engineer technology which enables us to extract vital resources from less nurturing worlds.

So far, humankind has traveled to only one other celestial body – the moon. The moon is like the person sitting next to you. To go to our next closest celestial body, Mars, we will have to travel all the way across town. Mars is about 16,000 times farther away than the moon, and that is when it is at its closest point to the Earth. [1] When Apollo 11 visited the moon, the crew carried all of the necessary supplies with them. They brought water, food and oxygen to supply the astronauts for their short 8-day mission. This amounted to hundreds of pounds of extra weight. In space flight, weight equates to money. It currently costs up to $14,000 to get a single pound into lower earth orbit. [2] The cost is even higher to take a pound beyond Earth’s orbit. Thus, cost prohibits sending resources from Earth to other worlds.

An alternative to costly shipping of resources is in-situ resource utilization (ISRU). ISRU is the act of harnessing and modifying natural resources from other worlds to provide basic necessities for life. Mars may appear to be a barren, lifeless wasteland. And it is. But trapped in that wasteland, are all of the ingredients necessary for survival. Mars has water trapped in rocks and polar ice caps. Mars also has oxygen, carbon and nitrogen trapped in rock and ice form. With the proper technology, humans could colonize Mars and many other celestial bodies.

But why would we? This technology will be expensive and time consuming to produce. What’s the point? The answer is three-fold. Science, growth and even survival.

We currently know almost nothing about the universe outside of our tiny, blue home. The scientific knowledge humankind would gain from space travel and colonization would be revolutionary.
Space travel can be analogous to the discovery missions throughout the 1400s to 1600s. Europeans discovered “the new world” and rapidly advanced scientific knowledge of navigation, biology, and the history of our ancestors. By enabling space travel, humankind would literally discover new worlds and the wealth of information they contain.

Colonizing another planet could also save millions, even billions of lives. Our planet has limited resources. Currently, 783 million people do not have access to clean water and 795 million people do not have enough food. [3] [4] Our planet can only support so many organisms, and yet the human population continues to grow. With in-situ resource utilization, the excess population could potentially colonize another celestial body where resources are unused. In addition, in situ resource utilization technology could be used to extract resources from the harshest locations on Earth. If we can learn to harvest water from the deserts of Mars, perhaps we can also harvest water from underneath the Sahara.

Not only could colonization save individual lives, it could ultimately save humankind. We know that Earth has a limited life time. Already, the planet has undergone five mass extinctions which killed the majority of organisms alive at the time. Despite scientific advances, the catastrophic events that caused these mass extinctions in the past are still unavoidable. The prevailing theory regarding the end-Cretaceous extinction that killed (among many other organisms) the dinosaurs, is that a massive asteroid impacted the Earth. If an asteroid was found to be on crash course with Earth today, there would be nothing mankind could do to save itself. The earth would be inhospitable for millions of years, and humans would stand virtually no chance of survival on Earth. [5] However, if we invest now in space travel and colonization using in-situ resource utilization, humankind (and perhaps many other organisms) could have a place to go when the worst happens.

While the earth has provided for man since the beginning of time, it may not always be able to sustain humankind. To ensure our continued survival, to save lives as we continue to grow as a population, and to advance the scientific knowledge of our society, we must pursue space travel and colonization. The only way to make colonization of another world possible is to begin engineering in-situ resource utilization technologies now.
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Responsibly Engineering the Midstream Industry

Hillary Knaebel

Engineers are constantly called to make decisions that have the potential to either negatively or positively impact our society, economy or environment as a whole. These decisions often involve a design choice of a certain material or method to complete their engineering package which ultimately has a greater effect than just on that project. For example, engineers in the midstream (primarily oil and gas pipeline and processing) industry are required to make decisions regarding the material and construction process of the pipelines they design every day. In order to “hold paramount the safety, health, and welfare of the public” [1] as well as the environment, engineers in the midstream industry should take the time to choose the right materials and methods for every project they design.

When designing a pipeline for gathering and transportation of crude oil, natural gas, or produced water from wells, engineers must choose a material and a size of pipe; both of which can affect the safety rating of the pipeline. For pipelines carrying crude oil, natural gas, or produced water, corrosion is a priority design criterion. This is so that the pipeline doesn’t fail and no cracks or holes are formed. If a crack or hole formed, a leak from the pipeline would be created; this would be very harmful to the environment or surrounding wildlife, especially if the pipeline is located near a water source that could be contaminated. A leak can also have a negative effect on the economy not only because they are expensive to clean up (increasing operational costs of a pipeline) but also because the leak could contaminate farmland and in turn reduce the supply of surrounding crops. An accident like this can be very harmful to the community surrounding the environment, and it is the engineer’s responsibility to do their due diligence and ensure that they have done everything in the power to prevent such a negative effect.

Leak prevention can be supplemented with leak detection software, such as Atmos Pipe, that statistically measure the probability of a leak using pressure and flow data [2], however engineers should be proactive instead of reactive in order to responsibly care for the environment, economy, and society. If engineers take leaks and corrosion into their initial design, they can also save operational maintenance money while making the pipeline as safe as possible. NAPCA, the National Association of Pipeline Coating Applications, sets some standards for corrosion and coatings on pipelines that are required to be met [3], but some materials are still better choices than others for use in pipelines. High Density Polyethylene (HDPE) plastic is a good material for produced water pipelines because it is corrosion resistant and its crystal structure also is resistant to crack growth [4]. This material is one of the most common choices for
produced water pipelines in the midstream industry; this shows that engineers have not been negligent in this aspect of the pipeline’s design. FlexSteel is also a good choice for these pipelines; FlexSteel is a more expensive choice but is very useful when both corrosion and strength play a role in the design. FlexSteel is a durable combination of polyethylene and steel materials that is used to create an extremely corrosion resistant environment [5].

Natural gas pipelines can also operate at very high pressures, making this another high priority criterion to ensure that the pipeline does not rupture and pose a risk to the environment or society. ANSI supplies equations for calculating the maximum allowable pressure of a gas and crude pipeline for different materials; these should be used in every design process of a pipeline to ensure that they are in compliance with Federal Pipeline Safety Regulations [6]. Engineers are also able to use hydraulic modeling software to ensure that their pipeline design is able to handle the expected flows without overpressuring. This software can be expensive; however, this is an important step of the engineering design process and it is necessary to be proactive in modeling these flows so that accidents are prevented. Taking this step can also end up saving money by once again reducing clean up or maintenance costs. High pressures make steel and stainless steel pipe an ideal option for natural gas gathering and transportation lines since they have high yield strengths and high allowable operating pressures.

Lastly, engineers should ensure that all of their designs are safe after they are constructed. Creating a hydrostatic testing procedure is part of the safe design of a pipeline in the midstream industry. These tests are developed to check and ensure the pipeline’s integrity before it is put into service. Hydrostatic testing evaluates the strength and find any defects in a new pipeline. It is the responsibility of the engineer to correctly develop a testing process by using test pressure to operating pressure ratios. If not designed or performed correctly, a pipeline could be put into service with pre-existing defects putting society at risk.

Each of these various materials for pipelines have recommended operating pressures, temperatures, corrosion and life ratings that engineers are responsible for evaluating when they are designing a pipeline network. Additional steps in the design process like leak detection software, testing procedures, and hydraulically modeling the flows of the pipeline are also important to consider even though they may take extra time or incur an additional expense. But it takes time to be a responsible engineer, and as engineers it is their responsibility to carefully evaluate all of these options. And, ultimately it is their responsibility unto society to engineer our pipelines with integrity so that they are safe and reliable.
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Becoming Radical Designers

Steven Kordziel

Floods, tornadoes, hurricanes, avalanches, earthquakes, fires, and terrorist attacks are among the concerns that face civil engineers when working on a new development. Before anything, it is the responsibility of a civil engineer to prevent loss of life in a design that is faced with some of the most violent forces of nature [1]. This emphasis on safety is what has driven the codes and standards that civil engineers are responsible by law to abide by in design. With the recent emergence of climate change and rapid consumption of natural resources, it is no longer enough for civil engineers hold safety paramount, but rather hold it paramount alongside environmental and societal concerns. Sustainable design considerations will become even more essential to civil engineers in the future. As defined by the Brundtland Commission, a meeting of the world’s leaders in 1987 regarding the future of sustainable development, “sustainability is to meet the needs of current generations without infringing upon the needs of future generations or compromising their abilities to maintain a similar standard of living with minimal environmental degradation” [2]. To be sustainable civil engineers must balance the needs of current generations (safety) with the needs of future generations (environment) while remaining competitive by providing economic design solutions. Often these considerations cannot be synonymous in a design and tradeoffs between safety and environmental impact occur. To work towards sustainability civil engineers need to redefine design hierarchy and focus on design implementations that allow safety and environmental synergy.

When making design decisions engineers tend to adhere to a design hierarchy, where certain implementations and practices are emphasized over others. Engineers incorporate this hierarchy to “develop a shape and arrangement that is agreed to best embody the operational principle” [3]. This chosen design that best embodies the operational principle is what will be defined as a typical design. There are, however, radical designs where “the operational principle and normal configuration are not known or the known ones are not used” [3]. A simple example of a radical design would be a car that is designed to be extremely fast. The typical function of a car is to provide a safe and efficient mode of transportation. By altering the hierarchy and placing speed as the governing priority, the design is altered to have a radical design by function [4].

When designing a building and the surrounding site development, civil engineers seek to develop a building that efficiently resists the forces of nature while supporting the form requested by the owner and architect. It is the goal of a building to be safe, durable, and cost effective. Developing an
An environmentally friendly building is a radical design. It is radical because it is outside the function that engineers are asked and required to design for. The only environmental considerations placed in the design hierarchy are a result of codes and standards that require environmental implementation or by a client that desires an environmentally friendly design. This hierarchy must be redefined to place an emphasis on sustainability. As discussed above, a design must balance the needs of the current and future generations [2]. In civil engineering, this means safety and environmental concerns must hold equal balance. There must be an incentive for engineers to be sustainable. Incentives such as Leadership in Energy and Environmental Design (LEED) are beginning to work towards sustainability by requiring engineers to consider environmental impacts as well as safety.

With an understanding of how design considerations can be altered, it is important to discuss how sustainable solutions can best be implemented to allow a balance between safe and environmentally friendly designs. On any project site there are many small designs that make up the overall design of the site. Many of these smaller designs involve tradeoffs between environmental impact and human safety. When choosing materials for force resisting systems it is the duty of a structural engineer to choose materials that he/she believes will best respond to the expected loading. Many buildings are designed to resist extreme loads, such as an earthquake, and are expected to keep human inhabitants safe. In these situations it is difficult to trade safety for low environmental impact when there are many uncertainties as to what forces will be felt by the structure. It is also important to consider the safety of craftsman building a structure. Many typical design methods are well documented and craftsman are familiar with how to safely implement them, while radical designs challenge craftsman to build buildings they are not experienced with. Materials and processes must be understood and be assured to perform as expected when implemented.

Given that materials or processes are well understood and acceptable for implementation, it should be the duty of the engineer to always choose a material or process that will have a lower environmental impact within a reasonable cost margin. These are implementations that can lead to better sustainability and are considered synergistic. For example, in areas where a vehicle collision is of concern to a structure’s stability, it is common practice to implement a concrete bollard to absorb vehicle impact before reaching the structure. A more sustainable and synergistic choice would be to plant trees in place of the bollards to deter impact [5]. Many of these synergistic choices can easily be implemented into a design to allow for a both safe and environmentally friendly solutions.
Balancing safety and environment while remaining cost effective may sound a bit farfetched, but some of the most innovative designs in modern civil engineering do just this. One such example is the Alfred A. Arraj Courthouse in Denver, Colorado. The courthouse was designed to resist blast loading as a precaution to terrorist attacks and still achieved a LEED Gold certification as a very sustainable building development. The building utilizes renewable materials, high performance window glazing, advanced energy and building controls, and a revised air distribution system to minimize its environmental impact [6]. In addition to this, the building can resist dramatic blast loads. The site is laid out to utilize typical grading features such as berms, drainage swales, and retaining walls to create a barrier from vehicles that are potentially carrying explosives [5].

Civil Engineering is pressed with many sustainability challenges. In order to create designs that are suitable for the current generation without detracting from future generations and degrading the environment, it is important to redefine design hierarchy to emphasize sustainability. This emphasis can be implemented with a synergistic approach where engineers find ways to combine safety and environmental impact reduction into mutually functioning designs. Civil engineers need to become radical designers in the fact they expand the scope of a project beyond only its function to incorporate sustainability. Many cutting edge modern developments have proven that this approach can efficiently be integrated. It is important for civil engineers of the future to look past typical design requirements and to strive to achieve sustainable design solutions. It is paramount that sustainability be a focus in civil engineering to prevent the depletion of natural resources and degradation of the environment.
References


As politicians, the public, as well as scientists and engineers advocate for the large scale use of renewable energy sources, we have to examine the broader impacts that such a shift will have on society and the environment. Solar panels are one of the major areas of renewable energy research and development. This essay will examine the impacts of the material choices in this area. It does not solve anything for science and society to switch from one unsustainable energy source to a different unsustainable source.

Solar energy is one of the most promising renewable energy sources that we know of. There are some largely negative effects associated with almost all other alternative energy sources currently. It’s well known how building dams for hydro energy can ruin ecosystems, negatively affect local populations, and restrict water access far downstream. Nuclear power is seen negatively by the public because of the potential danger and the waste produced. Wind power is a clean and powerful energy source with few negatives, but it takes up mass amounts of land and is very expensive to implement. Biomass is promising but is still in beginning stages of development. Solar energy is readily available all over the world, because the sun shines everywhere. Even in the far north and south it’s popular. After all, in the summer, there is sunshine almost 24 hours a day in those places. Solar energy still has some downsides right now though. The technology is still relatively inefficient which means it’s difficult to get the power needed from solar without a very large investment. Energy storage is also a major weak point, and typically chemical-heavy batteries are used to store energy unless the solar array is directly connected to the grid.

Increasing efficiency and decreasing manufacturing cost is the biggest focus in solar technology research, but it shouldn’t be. Right now, the biggest downside of solar energy is, believe it or not, the environmental and societal impacts of the manufacturing of solar panels. Currently, the vast majority of solar panels – over 90% in fact – are made with polysilicon [1]. These types of panels are generally thought of as very environmentally friendly because silicon is such a stable and common element. However, the environmental and societal problems with these panels are not because of the material but the actual manufacturing process. To start with, most silicon is collected from quartz mines, which has well known occupational hazards with high rates of lung disease in mining communities. The initial refining of the silicon requires a lot of energy to keep the furnaces hot, which creates its own carbon dioxide and sulfur dioxide emissions. The second step of the refining process to take the rough silicon and make it into polysilicon uses hydrochloric acid and hydrogen to in a series of reactions to come out with the desired
polysilicon, as well as the extremely toxic compound, silicon tetrachloride. In fact, unfortunately the amount of the toxic silicon tetrachloride produced in this process is usually three to four times the amount of useful polysilicon produced [1]. This waste material can be recycled to produce more polysilicon but the equipment is very expensive and some manufacturers have simply disposed of it. If done improperly, this can have catastrophic effects on local water systems. This potential for chemical pollution is one of the biggest downsides of solar panels currently. However, the situation is improving with China implementing a regulation that says manufacturers must recycle 98.5% of the silicon tetrachloride they make. NREL is currently researching the use of ethanol in the manufacturing process instead of chlorine based chemicals, but unfortunately, this is just one step of the whole process that uses dangerous chemicals and produces potentially dangerous waste.

Another solar panel technology is far less popular, but it avoids much of the chemical processing problems of polysilicon solar cells. These are called thin-film solar cells. The manufacturing process for thin-film solar cells does not use harmful chemicals, and it also produces less waste. However, there are still problems with these cells. There are two main types; cadmium telluride and copper indium gallium selenide (CIGS). However even the CIGS type uses cadmium sulfide in the second semiconductor layer, so both types contain cadmium, which is a carcinogen and a genotoxin. This is not so much a problem in manufacturing as it is in disposal after the life of the solar panel is over. Recycling of cadmium is strongly encouraged but it still ends up in landfills either for consumers’ convenience or because of their ignorance. This can create problems with the cadmium leaching into the soil and being transported from water. It is not a big problem right now, but the industry has to think ahead to what could happen if this type of cell became the dominant technology.

Another very promising cell technology being researched currently is Perovskite solar cells. These cells have many benefits. They are less bulky than silicon cells, and use very abundant materials, and at the same time being extremely stable they almost seem to be the cell of the future. The efficiency is still being improved but currently it provides stiff competition with silicon cells and is only a little bit behind the thin-film technology [2]. However, the one downside is that they currently use methylammonium lead iodide chloride. This presents potential manufacturing and obvious end-of-life problems as well, since lead is not environmentally safe. These are not mass produced yet so it’s impossible to know how large scale implementation of these cells would affect the environment or societies yet. However, if they do not present major problems, they could provide major benefits to the solar industry with cheaper, smaller high efficiency cells.
It is clear that we cannot take alternative energies at face value. There is much more to consider with any alternative energy we choose. Not only manufacturing energy usage and waste, and end-of-life waste, but also the impacts this could have on communities and economies. The goal of all this research is to have great positive impacts on the whole world. Cheap energy is often the source of economic stimulation, and it’s possible with an inexpensive source of electricity without the typical huge infrastructure investment, we could see great economic growth and societal growth in poorer countries without access to energy. Energy provides the more opportunity for better food access, medicine, water treatment, and the list goes on. In more developed countries, good solar cell technology will lead to a smaller carbon footprint everywhere, less chemical pollution, and less reliance on fossil fuels and other more harmful energy sources. It’s true that solar energy is abundant and practically endless, we just have to make sure that the broader impacts of our manufacturing and waste products are sustainable.

Citations


Why It Matters that They’re Turk

Sean McGinley

“See, I’m really glad that I am not in the honors program because now I don’t have to pretend that I care,” my friend casually stated to me as I told her about my class discussion on the lack of a scientific proof for race. She operated as indifferent to the social structures existing around us. My experience at the Colorado School of Mines has shown me that engineers try to remove themselves from the human aspect of design into what they believe to be a solely technical world. But, a semester’s course in cultural anthropology my sophomore year forced me to reconsider this dichotomous assumption. I could not believe that such a brilliant young mind could so easily disregard the human nature of engineering.

Throughout my time at the School of Mines, I have come to realize that engineers must understand all aspects of their design in order to fully succeed. This, at a minimum, includes the selection of materials to design to. A summer working in Barcelona taught me that a delicate balance lies between the most economical decision and the most feasible implementation. A class in the development of revolutions through the McBride Honors Program proved that material of a beautiful statue only means so much when held in the hands of an activist. A late night study session for Machine Design showed that a material may withstand an initial load, but lifelong usage of the same material may result in the death of innocent civilians. But, a five week internship between the corn fields of Germencik, Turkey tied together all aspects of material design.

Before understanding the implications of design in Turkey, I had to learn of the culture thriving in the country I suddenly found myself in. I quickly learned that tea time meant more than a deceased friend, that anyone can pick from the fig trees as long as they did not take too much and that cutting down an olive trees means a criminal sentence, yet, I constantly asked myself why. Why do the Turks value these traditions so much? Beyond the seemingly quirky laws, the Turks come across as very proud people. When asked why the company decided to build the emergency dumps ponds at half the requested size, the company officials responded with, “We are Güriş and we are Turks: of course we know how to build ponds correctly!” This mentality rang through much of our work and I had no idea why.

To understand this culture, I had to revisit my history books from high school. Up until 1920, the Ottoman Empire ruled modern-day Turkey with an iron fist [1]. The emperor controlled the land and allowed for little amounts of freedom [1]. After the downfall of the empire, eventually called the “old, sick man of Europe”, Kemal Atatürk took control of the country [2] [3]. Atatürk revolutionized the country and
slowly brought the new republic to rival the great powers of Europe through efforts such as establishing universal suffrage, abolishing religious orders, and finally fulfilled long-standing international treatises [3]. However, Atatürk eventually passed away in 1925 and the country slowly started to decline in economic power [3]. Though his face remained carved into mountainsides and on every desk in his country, his policies did not. In 1997, this changed. Turkey again thrust its economy into the competitive world market through restricting politician’s boundaries, changing the country’s prime minister, and addressing the country’s violations of human rights [4]. All of this allowed Turkey to sit as the world’s eightieth largest economy [5]. Turkey succeeded because of the people’s will. When the world turned its back on the developing nation, the republic learned self-sustainability and again became competitive on an international basis.

But, how does this impact the selection of materials? In short, the entire process requires a specific calculation of culture. At one point during my internship, a housing case for a motor broke and delayed the entire commissioning procedure for a geothermal power plant. When deciding the best course of action, the company I worked for and I had to determine the best path to proceed with. A German manufacturing company would make the best product in the quickest amount of time, but we would lose the trust of our Turkish client. Instead, we opted for a Turkish company based in the capital of Ankara. This showed our client that we too believe in the Turkish workforce that managed to reinstate Turkey as a world power. And, since Turkey relies on agriculture for over 25% of the yearly GDP, we knew that we could make somewhat of a sound environmental decision because the country does not want to negatively impact this sector of the economy [6].

At first, I did not understand this decision. Better companies made better products through a cheaper and faster means. Yet, we did not want to choose these options. We instead opted to select materials for our project that fit into the best long-term solution for the company. In fact, our client has already signed us to commission their next power plant without considering options from other competitors. As engineers, we understood the mechanics of the situation: we needed a motor housing with specific dimensions, allowable temperature ranges, and proper color schemes. But, we needed to know more to make the best decision for our product. The proper material for the Turks means rebelling against a system that constantly disappointed them and proving to the word that Turks do make the best products. This means more than the selection of the best technical solution to a problem. I needed to know these small, historical facts to commission the world’s largest two-phase flash binary geothermal power plant.
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Rare Earth Elements in Electronics

Ryan Patton

Electrical engineers are presented with many different options when designing a circuit. While component values and tolerances are often taken into account, the materials used to create those components are rarely considered. Nearly all modern electronics contain rare earth elements. Their superior chemical properties have proven invaluable to the advancement of modern technology. While these elements are often used in small quantities, their questionable supply can have a negative impact on the environment, economy, and society.

Despite their name, rare earth elements can be found all over the world. They are located in the earth’s crust, typically next to radioactive elements. This makes extraction an expensive process, as the elements not only need to be separated, but the radioactive waste also needs to be disposed of [1]. This process has been the root of numerous environmental concerns. Citing health and safety concerns, citizens of Malaysia recently filed a lawsuit to halt the operation of a local rare earth processing facility. The facility’s radioactive waste had been blamed for an increase in birth defects and cases of leukemia [2].

It is estimated that over 95 percent of the world’s supply of rare earth elements is produced in China. Other countries like Australia, Canada, and the United States have limited rare earth mining operations, but are not able to compete with the low prices coming out of China (due to the lack of environmental regulations) [1]. Recently, China has begun to cut back on rare earth exports, causing great economic concern. It is believed that all exports will be ceased within the next 10 years as a measure to protect domestic supply [3].

American electronics manufacturing companies depend on a stable supply of these elements. Without them, production of common electronic components would become much more expensive, if not impossible. The lack of these components would quickly have an effect on the everyday life of the average American citizen. Neodymium magnets are necessary for the motors in electric vehicles and wind turbines. Europium and terbium are commonly used in displays and lighting. Modern semiconductor fabrication relies on hafnium and tantalum to create critical components for billions of smartphones and computers worldwide. Fiber optics, commonly used for high-speed communication (like the internet), depend on the use of erbium [3].
While design engineers may not fully consider the current supply of rare earth elements, their shortage could prove catastrophic. Fortunately, there may be a rather simple solution to the impending crisis. According to David Boothroyd, author for New Electronics Magazine:

“In an age when metals like aluminium, copper, lead and tin have recycling rates of between 25% and 75%, it is estimated that only 1% of rare earths are recycled. Japan alone is estimated to have 300,000 tons of rare earths in unused electronic goods.” [3]

The recycling of neodymium magnets has recently started to gain traction. Unused computer hard drives can be manually disassembled rather easily. The magnets are then removed from the drive and placed into a container filled with hydrogen gas, causing the solid to break down into a fine powder. This neodymium powder is equivalent to what is collected from mined ore, after the removal of radioactive elements [4].

From an environmental standpoint, recycling of rare earth elements is much less costly than mining. There are no concerns about the removal of radioactive waste, or destruction of natural habitat. Economically, the front end expenses of recycling are currently greater than that of mining. This is due to the labor costs of workers collecting and manually disassembling the hard drives [4]. However, if China were to stop exporting rare earth elements to the United States, domestic electronics manufacturing would quickly come to a halt. This would cause economic implications much greater than the labor costs of recycling workers.

In conclusion, engineers must be cognizant of the materials used in their designs. If no changes are made, electronic designers may soon find that all of their work has become obsolete due to a lack of resources. Basic awareness, and simple steps like recycling, could prove the greatest defense against the impending rare earth element shortage.
References


Winning the War on Energy Poverty

Alyssa Spomer

Energy poverty is among the most highly debated fields within humanitarian engineering; however, even with myriad technological initiatives bombarding the field with new innovations, it remains one of the most widespread problems in the developing world. The issue, in large part, comes from the way in which these innovations are being designed, as lack of foresight into environmental, social, and economic impact has the potential to deem even the most promising technologies unusable. However, as energy poverty is so intertwined with those communities that it affects, designing for development becomes much more than weighing perceived impacts from an outside perspective. Rather, it requires a human-centered design approach to allow those most affected to determine design criteria as well as appropriately define the true impact of the project. The amalgamation of human-centered design and cognizance of environmental, economic, and, social impact is relatively new concept in the mechanical engineering field, yet those companies that have carried out this dualistic approach have seen great project success.

This is the case for the Nokero Solar Light technology. A product developed from people, for people, this technology has seen success in its early stages. Not only have the designers iterated their technology to best address needs of the community but the foresight they have placed in environmental, economic, and social impact as seen through a community lens have ensured project adoption and longevity. Although there are still impacts that have yet to be addressed by the Nokero light in this stage of the process, the company’s ability to hear the needs of the community and mitigate foreseeable impact defined by those effected has catapulted it to the forefront of the technological war on energy poverty.

Since its development in 2010, the Nokero Solar Light has revolutionized the way that the technological sector is combating energy poverty in the developing world. Although initially conceptualized by CEO and Founder, Steve Katsaros, as a means of improving construction site lighting, the solar light quickly transformed into a means of providing off-grid light solutions for developing communities [1]. With the goal of reducing kerosene use across the world, the Nokero light consists of four solar panels and five LED lights to provide six hours of battery life, all features which allow consumers to remain untied to inconsistent power grids and reduce reliance on gas light solutions [2]. The pocket-sized device can be configured into a hanging, standing, and personal light, allowing for versatility in use and application [3]. Since its introduction to the market, the product has utilized Lean Design for the Developing World (LDW), a methodology comprised of taking customer feedback and design suggestion
to iterate technologies [4]. This approach has ensured that the most effective and culturally appropriate
design is realized. And so far, it has worked. Currently Nokero has produced over 1 million solar light bulbs
and reached over 127 countries with a goal of expanding even further [5].

Although the iterative, LDW approach has directly helped Nokero understand their consumer
market more intimately, it has also allowed them to address the potential impacts of their technology in
the environmental, economic, and social spheres. By utilizing this LDW methodology in conjunction with
human-centered and impact resistive design, this product has and will continue to see success.

One of the most obvious impacts associated with the Nokero Solar Light project is in the
environmental realm, as the project’s focus is in eliminating kerosene need. In a majority of developing
countries, people rely on the use of kerosene as primary means of light. This, in turn, has heightened
indoor air pollution, creating both respiratory and sight problems, and accounting for approximately 4.3
million deaths per year [3]. Not only has the use of kerosene translated into lessened air quality but the
use of open-flame light sources has increased burns and structural fires in these communities [6]. By
eliminating the need for kerosene, the Nokero solar light principally has a positive impact on health, as it
decreases the main source of air pollution and reduces the threat of fires and other complications
associated with the fuel source.

However, while the environmental impacts appear positive, the new technology may not be
completely environmentally friendly. Because the lifespan on these products is approximately 5 years,
consumers will need to replenish their supplies, putting more waste into circulation and creating need for
proper disposal facilities [1]. As appropriate waste facilities also prove problematic in these communities,
excess and potentially hazardous waste coming from the devices present another component which could
hinder the world-wide acceptance. It is in this way that while the Nokero light appears to positively impact
the environment, it is not without flaws, requiring a more careful analysis and appropriate risk mitigation
procedures before the project will see wide-spread success.

While the environmental impacts of the Nokero light are mostly positive, the economic
impact of the design has more variability and as such, has become the aspect of the project that Nokero
has focused most on. In order to ensure project success, the main focus of the design was to reduce cost
below the price of kerosene. With the Nokero light selling at an MSRP of $15 and replacement light bulbs
sold in bulk at $6, the company has ensured that not only is the product more financially viable then
kerosene, but that it will pay itself off in six months or less [3]. This reduced financial strain has freed up
approximately "$27 billion to be spent on education, home improvements, and a range of other cultural
and social activities that result in a better quality of life" across nations that have introduced the technology [2]. Not only that, but the presence of these new devices have encouraged entrepreneurial enterprises, as Nokero's "business in a box kits - 144 bulbs along with displays and fliers" have fostered sales, increasing individual's incomes and allowing businesses to remain open later [7]

However, as in any business venture that has a goal of making a profit, the Nokero light has the potential to negatively impact the communities it is seeking to help. Because distribution to communities has proven difficult, Nokero has relied on second party sellers and organizations that have more immediate ties. While this has helped distribute products, it has also introduced another profit-seeking middle-man that may drive the $15 product up to $20 or more, making it "too expensive for the final customer" [3]. Similarly, the seemingly low price point of $15 is still not affordable for many of the poorest populations, a characteristic which may drive a wedge further between the poorest communities and the rest of the world [2]. Furthermore, the elimination of kerosene from the consumer market may inevitably put local suppliers out of business, creating small scale unemployment increase [2]. Because there are so many concerns in regards to economic impact of the device, Nokero is continuing to carry out extensive market research in order to ameliorate any negative consequences.

Although the economic impact of the device still remains a prevalent concern for future design iterations, the social implications, like the environmental ones, are almost overwhelmingly positive. By eliminating the necessity of kerosene lamps, Nokero is helping increase home safety and environments. Consistent with appropriate human-centered design techniques, Nokero surveyed community members during implementation and found that the amount of fire related home disasters had decreased [6]. Not only that, but the affordable and long lasting light sources were allowing students to "increase their study time by nearly 50 percent", a practice which has improved schooling throughout the communities and therefore helped to bolster higher qualities of life and a more educated populace [3]. Similarly, improved quality of light in the evenings has allowed communities to increase cultural practices, as not only can church service be held later, but community gatherings and other celebrations can continue into the evening [8].

However, the cultural impact may also be seen negatively, as the introduction of quality light sources in many off-the-grid communities have changed habits and therefore shaped cultural identities and practices. For example by increasing light availability, cultural characteristics such as hours spent awake and rising times could be altered [8]. This threat to traditional cultural practices makes wide-scale
adoption unknown; however, easily combatable if the proper surveying and consumer product testing is carried out in full.

With the complexity of engineering challenges of the modern world, it has become increasingly important for the use of appropriate human centered design techniques in conjunction with impact analysis. As demonstrated in the case of the Nokero light technology, by addressing impacts and solutions through a community centered lens, one can ensure appropriate measures are taken and the correct problems are identified. It is through this careful consideration of the duality of engineering design that the Nokero light has paved the way in humanitarian engineering and while the device still has problems to overcome in order to help eliminate energy poverty, there is no doubt that the future of solar light technology looks bright.
Works Cited


Notes
LOCATION PLAN - CECS SENIOR DESIGN TRADE FAIR

- Lockridge Arena
  - (see detailed layout below)
- Breakfast for 492 Students
- Judges Lounge

Suggested Access to Lockridge Arena for Most Senior Design Teams
(6' maximum width)

Alternative Access Route for Heavy, Wheeled Vehicles
(6' max. width)