FINAL SCIENTIFIC / TECHNICAL PUBLISHABLE REPORT

Recovery Act – Sustainable Transportation: Advanced Electric Drive Vehicle Education Program

DOE Prime Contract Award: DE–EE0002627

Colorado State University Ventures
Principal Investigator: Gary Caille Ph.D., P.E.

University Team Members:
Colorado State University
Georgia Institute of Technology

Community College and Education Foundation Team Members:
Arapahoe Community College

Industry Team Members:
Motion Reality Inc.
Ricardo Inc.

Collaborators:
Douglas County School District/Education Foundation
Gooru

March 12, 2014

Acknowledgement: "This material is based on work supported by the Department of Energy under Award Number 'DE–EE0002627'"

Table of Contents

1.0 Executive Summary

This is the final technical report for U.S. Department of Energy's National Energy and Technology Lab (NETL) Recovery Act – Transportation Electrification Grant DE–EE–00002627 for Advanced Electric Drive Vehicle Education Program: Plug–In Electric Hybrid Vehicle Education.

The collective goals of this effort include: 1) reach all facets of this society with education regarding electric vehicles (EV) and plug–in hybrid electric vehicles (PHEV), 2) prepare a workforce to service these advanced vehicles, 3) create web–based learning at an unparalleled level, 4) educate secondary school students to prepare for their future and 5) train the next generation of professional engineers regarding electric vehicles. The Team provided an integrated approach combining secondary schools, community colleges, four–year colleges and community outreach to provide a consistent message (Figure 1). Colorado State University Ventures (CSUV), as the prime contractor, plays a key program management and co–ordination role. CSUV is an affiliate of Colorado State University (CSU) and is a separate 501(c)(3) company. The Team consists of CSUV acting as the prime contractor subcontracted to Arapahoe Community College (ACC), CSU, Motion Reality Inc. (MRI), Georgia Institute of Technology (Georgia Tech) and Ricardo. Collaborators are Douglas County Educational Foundation/School District and Gooru (www.goorulearning.org), a nonprofit web–based learning resource and Google spin–off.

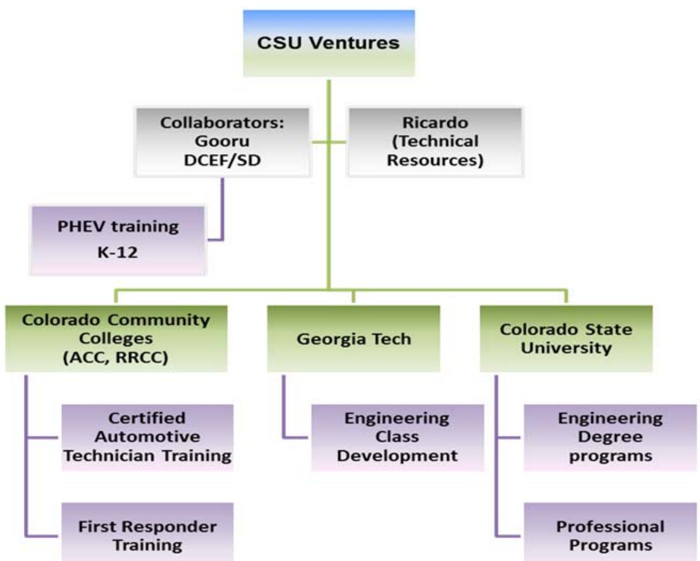


Figure 1: Team Organization and Responsibilities

The overall objective establishes a public/private partnership to accelerate the market introduction and the penetration of advanced electric drive vehicles by focused educational opportunities and increase community awareness. This public/private partnership will accomplish its objectives through: 1) the creation of educational and outreach materials for secondary schools with a focus on Science, Technology, Engineering and Mathematics (STEM) and the community focusing on under–represented populations (Native Americans, veterans and women), 2) the establishment of training programs for PHEV (PHEV includes hybrid electric vehicles and plug–in hybrid electric vehicles) service technicians, and emergency first responder and safety training and 3) the enhancing of engineering degree programs, creation of certificate programs and professional courses. Together, these efforts work to advance development of PHEVs, their components and associated systems engineering including support systems, safety systems and recharging stations. These objectives establish this electric vehicle initiative as a strong positioning resource for improving public perceptions and confidence in the U.S. auto industry.

Highlights of this effort are:

- CSU and Georgia Tech developed 8 courses teaching over 354 students during the granting period. ACC incorporated PHEV training into their nationally recognized automotive technician program and Red Rocks Community College (RRCC) incorporated first responder training into Emergency Medical Team (EMT), police and fire training programs. Over 286 students were educated through the community college programs. PHEV technical training was incorporated into high school automotive training programs, educating 191 students. Through grant–funded expos and conferences, approximately 965 middle and high school students received alternative fuel technology and STEM instruction and 186 educators received training to incorporate these topics in their regular coursework.
- Community outreach focus includes under–represented populations: Native Americans, veterans and women. The program held workshops for all of these groups and was instrumental in establishing a veteran’s office at ACC. Outreach to women occurred at the secondary school level, college level and at the workforce level. The team participated in numerous Native American workshops throughout the program, including attendance at major regional pow–wows. A long–term relationship was established at the Denver Indian Center (DIC) with PHEV technician training introduced as a new occupation for career–changing Native Americans.
- Industrial participation as service providers and technical consultants included Ricardo, Inc., MRI, Gooru and the National Fire Protection Association (NFPA). Ricardo, an independent global automotive design and engineering company provided consultation and expertise. Gooru provided website support and served as the archival source for outreach efforts and community storage. The team also worked cooperatively with the EcoCAR 2 team at CSU in providing community outreach and educational material to the secondary schools. As part of the first Responder education, CSUV licensed the NFPA’s first responder program and provided input to development of NFPA’s EMT and first responder training programs.

Sustainability of this DOE effort was established for most of the task programs independently, rather than as a comprehensive program, with the long–term benefits farther–reaching because of these multiple independent efforts. For example, the information and courses developed will continue to be offered at their respective institutions and will be continually tailored and improved to better serve the populations they are reaching. Key outreach material, including lectures, kits, video and papers, have been uploaded to Gooru and are available to the general public. Due to the accomplishments from this grant, additional funding was granted from a local foundation to continue training secondary school students and teachers. Follow–on grants were also obtained to continue outreach to Native Americans, veterans and local women’s organizations continue to provide strong support in fostering careers in STEM.

Other participants were added with approval as needed. For example, ACC subcontracted to RRCC Fire Academy to provide the first responder training modified to include PHEV and licensed by CSUV for this education. The course was licensed by CSUV from the NFPA to provide consistent national training for this subject.

The focus areas of the program are managed as separate projects as well has part of the whole. Quarterly program review meetings bring all the projects together for information distribution and status review. A monthly project status report was requested of each subawardee. Additional quarterly reporting for both DOE management and American Recovery and Reinvestment Act (ARRA) requirements are being provided.

2.0 Objectives and Key Accomplishments

2.1 Outreach

Objective:

> *To create an inclusive customer/student/manufacturer environment that is not only technical, but incorporates policy, environment and business. Outreach will foster "Experience 9 to 5," or working environment which is a career exploration program for high school students and other opportunities to Native Americans, veterans and women's groups and other under–represented populations in automotive technician training with an electric vehicle focus and basic safety requirements.*

The program met its goal to develop and disseminate PHEV education. This team developed means to distribute electric vehicle and PHEV knowledge and educational demonstration for a broad community. Working with various educational organizations, new educational materials and technical education infrastructure for outreach to students were initiated. Online interactive distance learning is using Gooru as the online vehicle. Outreach extended to the under–represented populations (Native Americans, veterans and women). Initial planning and findings from focus groups quickly dictated that outreach efforts among all post–secondary populations were most effectively focused through social media channels and opportunities for face–to–face and hands–on experiences.

K–12 and community outreach materials were developed using PHEV as the topic to engage students and teachers, with a strong STEM focus embedded within the materials. Outreach to adult populations who are under–represented in the industry was geared more toward PHEV and sustainable energy technologies as career opportunities–fields that they may not have considered, but certainly fields in which they could excel.

To optimize the utility and sustainability of all materials developed, the Program constructed an online environment that leverages the educational materials constructed for local community outreach toward achieving a national impact (see **Key Project Activities**). K–12 materials were delivered through Gooru, an open and interactive online teaching and learning platform for educators and their students. All outreach goals were met. Accomplishments against the task goals are summarized below, with more detail offered under **Key Project Activities**.

Accomplishments:

- *"Career Connect"* provided middle school and high school populations an in–person career exploration program with strong automotive technology and renewable energy tracks including PHEV. *Career Connect* provided career education programming for five semesters, involving 663 students from 15 Denver metropolitan area high schools.
- *"Career Connect: 8th Grade Expo"*, reached more than 4,000 8th graders from 15 middle schools in this career exploration fair. The Expo featured 84 employers in a variety of industries– military, skilled trades, automotive technology, engineering, IT, natural resources and energy.
- Native American, veteran and women were coupled with social media for practical exposure to the PHEV automotive field through car care clinics that catered to each. Relevant spokespersons were recruited from each target population and were actively included in live outreach at career expos, tradeshow and outreach events for a personal approach, together with their activity on social media. Social media sites were established and online communities fostered through them leading up to and following each of three car care clinics; a mobile app was developed for the veteran population at ACC.
- Three car care clinics were held on–site at ACC with up to 10 participants in each clinic.
- Distribution of over 350 Regenerate! Activity kits for classroom instruction.
- Three Workshops were conducted for teachers for PHEV training into the classroom.
- Outreach Planning and Coordination meetings were held throughout the grant period to ensure a focused and coherent outreach plan would connect to targeted audiences and connect with other outreach partners with related endeavors and projects. This resulted in integrated traditional and non–traditional outreach efforts to schools and general community events. During the granting period, the following 11 organizations worked on community and school outreach events and materials–
    - College of Natural Sciences Education and Outreach Center (CSU)
    - Center for Multiscale Modeling of Atmospheric Processes (CSU)
    - EcoCAR 2 Vehicle Innovation Team, Dept. of Mechanical Engineering (CSU)
    - Gooru
    - Northern Colorado Clean Cities
    - Denver Metro Clean Cities (Project FEVER: Fostering Electric Vehicle Expansion in the Rockies)
    - Drive Electric Northern Colorado (Electrification Coalition)
    - Douglas County Education Foundation and Douglas County School District
    - Poudre School District
    - Society of Women Engineers Rocky Mountain Section
    - Northern Colorado Business Report.

- A variety of opportunities and venues were used for information transfer advocating electric vehicle utilization and advanced vehicle understanding in the community.

2.2 Technical Training Automotive Vehicle Maintenance and Technical Training

Goal: *To expand and supplement already approved automotive technician training programs by adding courses for present students and developing supplemental one week courses for practicing professionals to upgrade their knowledge and skill in maintaining PHEVs. Develop step–in motion capture virtual reality to improve and expand the complex maintenance training. Explore opportunities to export this education and training.*

Educational facilities enhancements were keys to facilitating training on PHEVs. This program has developed an advanced electric automotive vehicle technician training program at the campus of the nationally recognized Automotive Technology Department at ACC in Littleton, Colorado. ACC developed a short course version for technicians already in the workforce to update them on PHEV vehicle maintenance procedures. ACC worked with Douglas County School District Ponderosa High School to incorporate PHEV training into the high school's automotive training program (considered co–enrollment with ACC). The project initially procured six vehicles for student use in this training program (and two more later). CSUV licensed the NFPA first responder courses. In cooperation with NFPA, ACC modified the NFPA courses for Paramedics/EMTs and Police. RRCC, which has the Colorado Fire Academy, offered the training / course work.

Figure 2: Functional Organization

Accomplishments:

- ACC purchased the equipment necessary to update the ACC teaching facility in support of the project's programs. Specifically, ACC initially acquired six PHEVs (two others later), multiple tool sets, repair manual software, diagnostic equipment associated with the service and repair of those vehicles, safety gloves, eyewear and protective clothing associated with the servicing of the new vehicles
- ACC made its Advanced Automotive Center available to conduct both project–based academic and workforce development training programs.
- ACC developed two 2–day PHEV service and repair training modules, integrated them into ACC's academic auto technology program and developed and implemented a marketing campaign to attract automotive service and repair professionals to a workforce training program using the two home–grown modules with mixed results.
- RRCC integrated the PHEV inclusive NFPA curriculum into its Occupational, Health and Safety course for firefighters in addition to the previously integrated the modified and approved NFPA PHEV Safety modules into their EMT and Law Enforcement academic courses. A total of 84 participants in 12 participating fire departments in Colorado received the NFPA PHEV Safety modules as part of their Fire Academy academic courses.

- ACC conducted auto tour workshops for Native Americans, veterans and women at the ACC automotive center to attract these demographics into ACC's PHEV academic program or workforce development PHEV service and repair program. Up to 15 participants attended each session.
- ACC secured ten first responder training sites located across the State of Colorado including: Denver, Colorado Springs, Fort Collins, Greeley, Littleton, Boulder and Grand Junction; scholarships at three training sites were obtained from Denver Metro Clean Cities Coalition Project FEVER (Fostering Electric Vehicle Expansion in the Rockies).
- In early March, 2012, the development and marketing of the EMT and law enforcement first responder course was continued to increase its focus on attracting Native Americans, veterans and women into the program. These efforts were met with some success in the development of specialized PHEV Clinics for all three groups having an average attendance of eight participants per session.
- ACC offered EMS first responder training at Cimarron Hills Fire Department in Colorado Springs, with 15 participants attending. This was the first off–site EMT program conducted in Colorado.

2.3 University Level Education

Goal: To develop comprehensive educational requirements documents and subsequent course plans to address PHEV requirements. The course plan will address undergraduate and graduate level education and professional level education short courses. Courses were then to be established at each of these levels.

The project achieved this goal as shown in the accomplishments listed below. The Team partnered university and industrial expertise for undergraduate, graduate and postgraduate course development (see http://www.engr.colostate.edu/me/PHEVe/devel.html).

Accomplishments:

- Twenty–four articles and proceedings were published and 14 theses supervised (12 MS, 2 Ph. D) at two universities
- The program developed two undergraduate, four graduate and two short courses at CSU's Mechanical Engineering Department and Georgia Tech's Woodruff School of Mechanical Engineering
- Total students enrolled in PHEV courses at the contract end is 354; 254 undergraduate and 100 graduate.

2.4 Project Management and Planning

Goals:

To provide overall programmatic management and technical integration: Lead a requirements definition conference; determine the educational requirements that need to be formalized in the educational program and where they should occur. Assess the present curricula and syllabi for shortcomings. A technical roadmap will be developed that will shape the education plan. A similar outreach definition conference will be facilitated so as to develop the outreach plan. CSU Ventures, in concert with DOE and industry will develop a series of metrics using "six sigma like principles" that will allow the Government and industry to fully quantify the impacts of these efforts and determine where improvements must be made. Address the effectiveness of the program rather than just the number of courses or short courses developed or students enrolled.

Accomplishments:
The Team worked with industry representatives, subject matter experts (SME), first responders and educators to ensure proper content for all courses.

- All required reports, briefings and deliverables were submitted on time. A DOE equipment audit was completed in 2012 during which all equipment was accounted.
- The Principal Investigator provided guidance to the West Virginia University NAFTC effort as a Board of Advisory Member.
- The project team presented at the DOE Annual Merit reviews in 2010, 2011 and 2012.
- Work was accomplished within budget.

3.0 Key Project Activities

3.1 Outreach

Primary methods of communication were agreed upon and established at the planning meetings to ensure timely and efficient communication among all parties at all locations. Primary channels were to include email for routine communication, Dropbox for transmission of graphics and documents and Basecamp (online project planning program) for planning within project teams.

Three major planning meetings were held:

- May, 2011: Major objectives were established for CSUV and partners through June, 2012.
  - Corporate stakeholder identification for potential support or sponsorship
  - Clarification of target populations and the communication methods most effective for
  - Crafting major messaging from Focus Groups and stakeholder interviews
  - Establishment of communication channels appropriate to the targets
- June, 2012: A finer point was placed on the research completed in the first year and detailed execution was planned for all participants and contractors through Q2 2013.
  - Recruitment of role models/spokespersons within target populations
  - Development of core campaign content–coordinating both online and off–line approaches with consistent look, feel and messaging

- Development of admissions and financial aid information packets for underrepresented populations
- Active participation with potential collaborators, industry and government organizations
- Planning and execution of live events
- Planning online campaigns

• December, 2012: Planning for the no–cost extension of project activities was completed, predominantly comprising continued execution of outreach activities and adjustment of online approaches to be executed through June, 2013.
  - Continuation of industry and outreach events, high school, university and education and job expos
  - Continued active participation in trade and government organizations appropriate to the industry
  - Continuation of car clinics focused on target populations
  - Active maintenance of social media communities

Online tools:

- www.goorulearning.org
- http://www.engr.colostate.edu/VEEP/programs.html

The websites referenced within this task are listed below and all will be maintained after the grant's period of performance:

- Collection of Educational resources on Gooru– "Hybrid Electric Vehicles and Beyond"
- http://www.goorulearning.org/#collection-play&id=be7a5a89-e4fd-44a6-8c39-2b317246dfb5
- Vehicle Electrification Education Program website: http://www.engr.colostate.edu/VEEP/
- Hybrid Electric Vehicle Education (University Level Education) http://www.engr.colostate.edu/me/PHEVe/
- EcoCAR 2 CSU http://www.engr.colostate.edu/me/pages/undergraduate/senior-projects/ecoCar-2/EcoCar2-1.html

3.1.1 VEEP Central Outreach Website and Master Community Site

Grant project activities overall were referred to as the Vehicle Electrification Education Program (VEEP). The primary VEEP website was developed and maintained to provide a platform for announcements of outreach activities, workshop opportunities for K–12 educators, educational materials (videos, lectures and slide sets) and links to other non–profit groups involved in PHEV education and outreach. VEEP was also coupled with CSU's EcoCAR 2 program to serve as a launching point for community blogs and forums about advanced vehicles, local outreach events and EcoCAR 2's activities.

Figure 3: Vehicle Electrification Education Program Logo

Instead of simply uploading all of the program's educational materials and resources on the VEEP website, this collection of educational resources was also posted on Gooru. This served a dual purpose:

first, to attract teachers and their students from across the globe, but second, to reinforce the value of this information as core content to educators to use in their STEM classes. By providing a collection of resources about advanced vehicles at a site that teachers use to learn from as well as to teach from, the collection also served as an additional channel for online marketing. Professional development workshops and outreach events for teachers were also posted on the local Poudre School District *Share It!* website (https://www.psdschools.org/partnership-and-volunteer-center/share-it), for local teachers who were searching for engineering/STEM activities and educational resources provided by this outreach program.

Once the project was underway it became apparent that one website would not be the most effective manner to reach the project's disparate target populations. Online communities have evolved drastically over the last five years and are now much more finely tailored and individualized to their own participants. Word of mouth advocacy and a generally younger audience population dictated that websites should be augmented with the use of social media channels that directly reach target audiences and allow them to interact with the project team and with each other.

As described previously, the VEEP website (Figure 4) is the primary PR 2.0 online marketing channel used for advocating PHEV core content to K–12 teachers. VEEP is an international website hosting a collection of resources about advanced vehicles that teachers use to learn and also from which they can teach. Videos of lectures with accompanying slides from the Professional Development Workshop for teachers about "Energy, the Environment and Transportation" are available on this website.

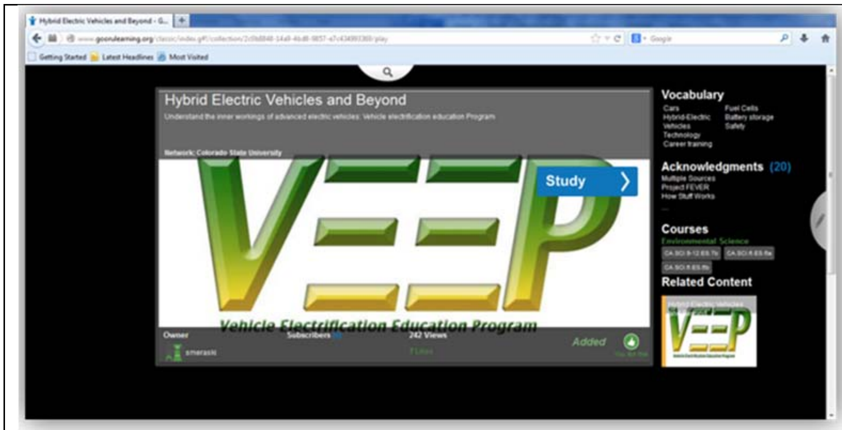


Figure 4: Vehicle Electrification Education Program Website

Marketing to Under–Represented Populations: Native Americans, Veterans and Women

A more customized and personal approach was determined to be the most effective means to communicate with the target populations. Since each group was different with cultural specific issues, problems, history, public opinions and policies unique to their situations, CSUV conducted focus groups to determine in detail the most effective way to reach and then communicate with these specific under–represented populations. The project then matched these focused educational opportunities with the development of online communities and publicized educational and outreach events through those online communities. Spokespersons were recruited from each target population. Spokespersons took part in interviews and roundtable meetings at both ACC and CSU to review the automotive technology and engineering programs and to discuss the nature of outreach activities and materials that would be appropriate to the populations they represent.

Native Americans:

Focus group participants agreed that hearing from members of their own culture was the most appropriate and effective way in which to approach this demographic. This is particularly true when that approach is made in familiar and trusted surroundings and from their own peers. The Native American Facebook page shown in Figure 5 is a very active group online, mostly due to the active participation of selected spokespersons, who were highly trusted members of the local Native American population. This serves present see ideas and then pull together the community and enables CSUV and ACC to fill the event that was publicized through the site.

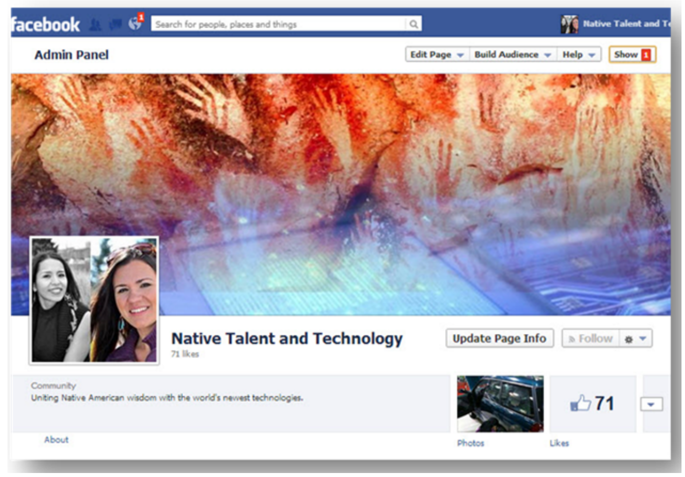


Figure 5: Content developed: "Native Talent and Technology"

Veterans:

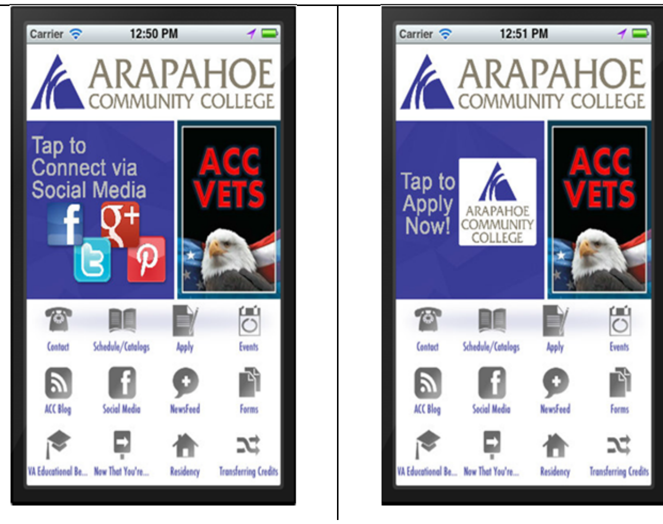
Online channels were established also for veterans and the same look and feel used to publicize events as well, but with messaging that would appeal to a military demographic. The Veteran's Facebook channel (Figure 6) is augmented with a mobile application as well, as project research indicates this is another effective way to communicate. Research also indicates that it would tie in well with the fact that at one host college, ACC, a popular veteran's lounge existed that would serve as a "check–in" point for veterans with smartphones. Veterans were the most clearly "definable" among the three target populations and so lend themselves well to the use of a functional mobile app.

Figure 6: Veteran's Facebook Channel

Screen shots of the mobile app are shown in Figure 7. The home screen has a dynamic image on the left side that alternates between options to hop on to ACC social media channels, or for prospective students to jump to pages that facilitate application.

Additional options included in the first lower panel include:

- Social media sharing
- Residency information
- Credit transfer information
- Newsfeeds (with easy links to the original articles online)
- An Events button that automatically updates to all events posted to ACC's own event website
- A listing of schedules and course catalogs from all ACC campuses.



Dynamic image on left side of home screen panel

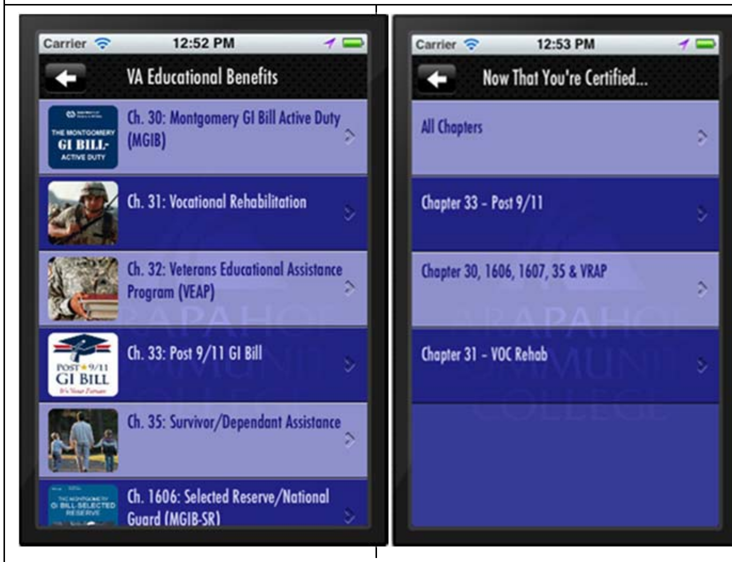


Figure 7: VA Educational Benefits Channel

Buttons on the lower panel of the home screen lead the veteran to information useful for investigating benefits and then on to more options to investigate once they're certified. All icons lead to areas where information is summarized, with an option to go to a complete web page. For example, the images shown Figure 7, the screens displayed when pushing the button for "VA Educational Benefits" to show additional information for veterans under "Now that you're certified".

Women:

Accordingly, social media channels and print material were generated that were targeted toward women, with the same look and feel between online and offline materials for consistent branding. The primary social media focus was Facebook. Social media and online marketing was used extensively prior to events, including the ACC hosted automotive clinics to promote to the project's target populations. A concerted and coordinated campaign using all methods prior to a clinic (using email marketing, collateral distribution, social media marketing and personal outreach) is highly

Figure 8: PHEV Women Facebook Channel

recommended and is what resulted in the most successful clinic with Native American participants. In the project's experience, successful recruiting will require a consistent presence and engagement to attract individuals from all target populations.

3.1.2 Core Materials Generation for Outreach Events

K–12 Teacher and Student Educational Outreach

The program generated Workshops for K–12 Educators as well as STEM–based activities for use in the classroom or in youth clubs. The activity kits introduce energy transfer and regenerative braking in advanced vehicles in an interesting and fun format for young people to relate to and understand. Top level understanding and technical information regarding electric and hybrid vehicles was provided for both community programs and K–12 programs in the form of brochures, posters, activity kits, lecture presentations, group discussions and tours. Lectures provided during teacher workshops were captured and uploaded to Gooru, the VEEP website and YouTube (www.youtube.com). Mathematics problem sets were created using PHEV as a backdrop, distributed to teachers and also uploaded to Gooru for easy access.

Figure 9: Regenerate! Activity Kit

Regenerate!

Regenerate! is a hands–on activity kit created for K–12 age youth to explore the energy transfer and regenerative braking in advanced vehicles. Educators use the kits to introduce the inner workings of PHEVs and they are also an effective tool for engaging students in new technologies, for enhancing their critical thinking skills and for initiating discussion about the environment, energy, transportation and technology. The kit is designed for use in a classroom or group setting to support STEM–oriented activities across disciplines (Figure 9). Regenerate! kits can be modified and tailored for each class' needs, so they can be offered to elementary, middle and high school students. The kits enable students to examine electron flow, electricity and magnetism, motors, generators, energy storage and batteries. The Regenerate! kit has been used in team visits to K–12 classrooms, during community events and during workshop sessions with educators. The kit is easily stored and several kits can be easily transported at one time. Three hundred and sixty kits were created and 350 of these were sent to interested teachers, outreach extension specialists and museum owners in 14 counties across

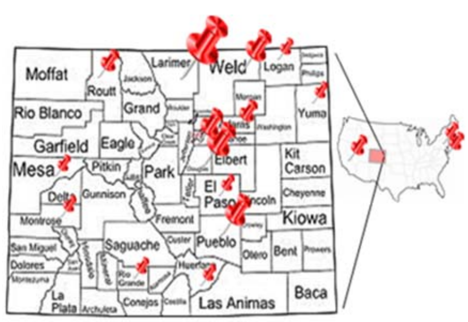


Figure 10: Distribution of "Regenerate!" Regenerate! Classroom Kit

Colorado, California, Washington, D.C., and Pennsylvania. See Figure 10.

A set of 14 kits are housed at CSU's Department of Natural and Environmental Sciences Education and Outreach Center for local teachers to "check out" and return after using them in their classrooms. See Figure 11. Twenty–five kits are used by outreach representatives of CSU's Mechanical Engineering Department (comprised of college engineering student members of the Vehicle Innovation Team/EcoCAR 2) and the remaining kits will be shared with other interested educators. See Figure 11. The core content of the kit is aligned with national and state educational standards, so they can be readily accepted by educators regardless of location.

Figure 11: Outreach Presentations to local Schools Using CSU College Students and Faculty as Mentors

Poudre School District Outreach, Fort Collins

The program outreach coordinator and members of CSU's EcoCAR 2 group conducted presentations and demonstrations using Regenerate! Activity kits at numerous schools. Lasting from 60 to 90 minutes, these presentations will be continued in the Poudre School District in the coming year in collaboration with CSU's Department of Mechanical Engineering. With new funding just received through a Pharos Fund grant from the Bohemian Foundation, additional Regenerate! activity kits will be created for use in continued presentations through the next year. Table 1 shows the outreach calendar and events.

Table 1: Poudre School District Outreach Events

School Event	Attendance	Date
Preston Middle School Brown Bag Lunch (seminar presentation by Dr. Bradley, EdoCAR2 faculty advisor and Co–PI on this grant)	15 6th–8th grade students	November, 2012
Timnath Elementary School	50 4th and 5th graders	April, 2013
Blevins Middle School	32 middle school students	April, 2013
Harris Bilingual Elementary School	20 elementary students	April, 2013
Fossil Ridge High School – CSU Innovations Breakfast "From Plug–In Cars to Fuel Cell Planes" (seminar presentation by Dr. Bradley)	20 high school students	October, 2013
Fossil Ridge High School's FRESH Club (Fossil Ridge Energy and Sustainability High Club)	20 high school students	November, 2013

"Hybrid Electric Vehicles and Beyond"– Online Educational Resources

Fifty–nine educational resources from more than 20 sources were collected and uploaded online to Gooru for ease of access to both teachers and their students. (http://www.goorulearning.org/#collection-play&id=be7a5a89-e4fd-44a6-8c39-2b317246dfb5) The educational material originated from highly respected contributors, including MIT, CSU, Penn State, DOE, NREL, How Things Work, Discovery, Project FEVER, Teachers Domain and PBS, among others. The Gooru site provides K–12 teachers with a one-stop repository of material related to vehicle technology, the environment and energy, along with fundamental mathematics and science principles. Teacher Workshop lectures, their accompanying slide sets, interactive websites, quizzes and core content on electric vehicles can be used by teachers to learn more about the field, or educators can teach directly from the online resources in their classrooms. Teachers can pick and choose from resources on the site, creating their own custom "collections" relevant to their courses. See Figure 12.

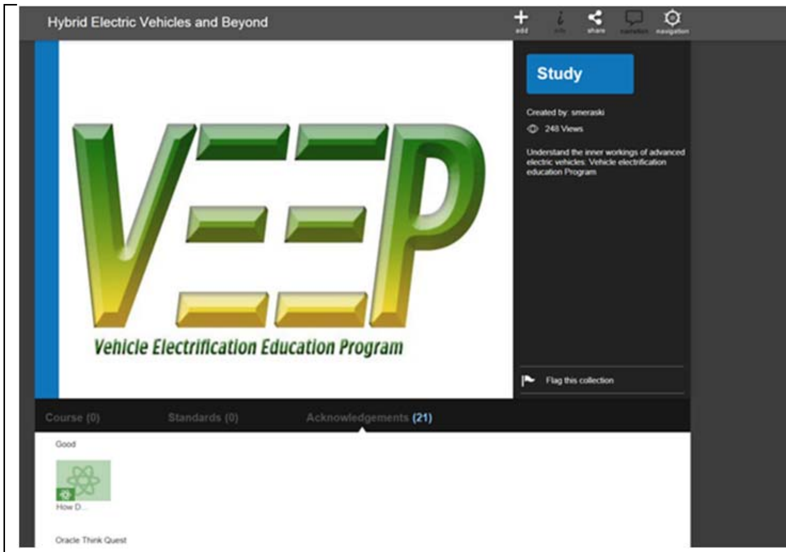


Figure 12: VEEP Gooru page

The "Hybrid Electric Vehicles and Beyond" Collection is aligned with several California State Educational Standards. Since its online publication in mid–September of 2012, the Collection has had 245 views. Since Gooru is a dynamic and interactive site, content can now be constantly tailored and refreshed with new resources and collections. The "PHEVs and Beyond" collection was one of the first educator collections to be hosted on the site and was the largest collection created to date.

Mathematics Problem sets for Middle and High School

The program collaborated with the EcoCAR 2 Vehicle Innovation Team of college engineering students to create mathematics problem sets using PHEVs as a theme. This booklet of mathematics problems was then distributed to teachers at the Energy, the Environment and Transportation Professional Development Workshop for teachers (see below) as well as uploaded to Gooru as a resource as well as part of the "Hybrid Electric Vehicle and Beyond" Collection (Figure 13).

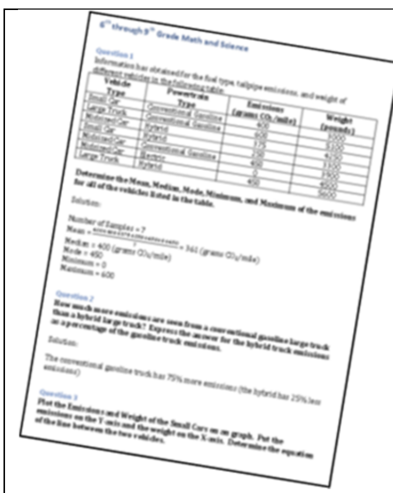


Figure 13: PHEV Math Workshop

"Career Connect" provided middle school and high school populations an in–person career exploration program with strong automotive technology and renewable energy tracks including PHEV.
Demonstrating true public/private collaboration, local and regional employers participated strongly in the program, providing career exploration programming related to PHEV/renewable energy topics to students. These employers included:

- Hanksville Hot Rods
- Douglas County Fleet Management Division
- American Honda (West Central Training Center) – provided safety training on PHEVs
- ACC's Automotive Technology Department
- Schomp Automotive
- Shaw Group – provided a "Power and Energy" session that covered careers in the field of renewable energy
- Lockheed Martin – hosted an engineering session that included an interactive project on auto design and electric power cells
- Larkspur Fire and Rescue – provided a session that included PHEV rescue safety.

The *Career Connect* 8th Grade Expo featured 84 employers in a variety of industries including: military and government, skilled trades, science, technology, engineering, IT, natural resources and energy. One employer (Intermountain Rural Electric Association) brought an electric car for the students to explore. Others brought displays about renewable energy (Ameresco, EcoTech Institute). In addition to sponsoring the event, ACC also had a booth at the Expo. Additional expos and institutes were held throughout the granting period to provide teachers and the public with opportunities to learn about sustainable energy technologies, the PHEV industry and STEM instruction. These were excellent forums in which to use the tools and capabilities developed through the grant and in which to foster connections between the public and private sectors active within the field. See Figure 14.

Figure 14: EXPO for PHEV

Douglas County School District's West Support Center, Castle Rock, CO May, 2011
Attendance: 32 teachers in May, 2011
The program's Educational Outreach Coordinator was invited as a panelist and presented background to district teachers on how to incorporate PHEV topic into the classroom (included interest survey for teachers for upcoming workshop).

Clean Energy Supercluster and Cenergy Expo
Colorado State University, Fort Collins, CO April, 2012
Attendance: 100 educators and community members
A poster was presented at the Expo describing this multifaceted Vehicle Electrification Education Program and showcasing Regenerate! activity kits. This annual university event promotes connections among CSU faculty and student researchers, the clean energy industry, the government and others.

Colorado Rides Electric Day in Steamboat Springs, CO
Routt County School District, May, 2012
The Northern Colorado Clean Cities representatives used the Regenerate! kit for lively interactive demonstrations to educators and students about energy transfer and regenerative braking in advanced technology vehicles.

Poudre School District Career and Technical Education Summer Institute; Kinard Middle School, Fort Collins, CO June, 2012 Attendance: 10 teachers
STEM concepts were presented by using the PHEV as a "vehicle" to engage students. Slide presentations and a lecture, "From course assessment to redesign: a hybrid–vehicle course as a case illustration," were discussed with pre–engineering middle and high school teachers. A classroom demonstration about energy transfer and regenerative braking (using the Regenerate! kit) was also used to introduce the topic as shown in Figure 15. Sets of eight to ten kits were distributed to interested teachers to take back to the classroom for use with their students.

Figure 15: PHEV Summer Teacher Workshop

Professional Development Workshop for K–12 teachers: "Energy, the Environment and Transportation" CSU Education and Outreach Center, Fort Collins, CO July, 2012 and spring 2013 Attendance: 11 teachers, 1 other
The Program created and conducted two 4–day workshops to deliver PHEV core content knowledge to middle and high school educators and assist them in incorporating this knowledge through classroom or after–school activities, demonstrations and exercises. Educators had the opportunity to discuss the underlying science and mathematics principles introduced in the core content and its incorporation into a lesson plan in their classes. See Figure 16. Gooru was introduced to educators and actually implemented live at the workshop. Representative educators from four county school districts in Colorado participated in the workshop (Weld, Larimer, Denver and Douglas counties) and created their own Gooru collections of resources for their own classes using the "Hybrid Electric Vehicle and Beyond" Collection (described above) as a template.

Figure 16: Energy, the Environment and Transportation Workshop

Along with a series of lectures and demonstrations of activities for the classroom, educators were also able to tour the Platte River Power Authority's Rawhide Energy Station (coal–fired steam and co–located natural gas turbine power generation), CSU's Engine and Energy Conversion Laboratory, EV charging stations from the Eaton Corporation and vehicles brought to the workshop (Chevrolet Volt, Nissan Leaf) from ACC's Automotive Technician Program. The EcoCAR 2 team and an instructor from ACC conducted the "hood up" tour of the vehicles followed by a spirited discussion period. See Figure 17.

Seven of the workshop lectures were captured and produced by CSU's student–run television station, CTV11. Four undergraduate students took part in the production. These videos were uploaded to YouTube, the VEEP website and Gooru as part of the "PHEV and Beyond" collection.

Figure 17:PHEV Workshops with CSU

The following faculty and professionals presented on key topics in the workshop:
Where possible, the number of YouTube views is indicated (the percentage of U.S view is shown parenthetically).

- Dr. Thomas Bradley, Department of Mechanical Engineering, CSU
  - Introduction to Hybrid Electric Vehicles–Motivation and History; YouTube: 450 (39%)
  - Hybrid Electric Vehicle Architectures; YouTube: 356 (37%)
  - Electric Drivetrains–Introduction to Internal Combustion Engines and Electric Propulsion; YouTube: 2113 (18% US; 36% India)
  - Energy Storage–The basics Renewable Transportation–Vehicle Emissions and Environmental Impact; YouTube: 64 (58%)
- Dr. Ken Stanton, Department of Mechanical Engineering, CSU
  - Designing a Hybrid–Electric Vehicle Program: input on 21st century workforce skills
  - Hybrid–Electric Vehicles and Regenerative braking: YouTube: 888 (30%)
- Dr. Amy Prieto and Mr. Everett Jackson, Department of Chemistry, CSU
  - Inexpensive, Efficient Approaches for Energy Storage–Li–Ion Batteries; YouTube: 1153 (30%)
- Mr. Dave Petruska, Engineering Manager, Woodward–Natural Gas Engines, Ignition and System Engineering; YouTube: 841 views (38% U.S)
- Dr. Ray Duthu, Department of Mechanical Engineering, CSU–Challenges Faced–Power Generation, Transmission and Distribution
- Dr. Cynthia Smeraski, Science Education and Literacy Programs, consultant to CSUV
  - Capture Energy–Regenerate! Classroom demonstration about regenerative braking and energy transfer
  - Incorporate PHEV core content for the classroom: Gooru approaches to "PHEVs and Beyond"

    - Electric vehicles as a topic for applied school Mathematics
- Dr. Andrew Warnock, College of Natural Sciences Education and Outreach Center
    - Get Energize! classroom activity kit about making rechargeable batteries and solar cells
- Mr. Dan Zimmerle, Department of Mechanical Engineering, CSU's Engines and Energy Conversion Lab
- Mr. Brad Kiehne, Plant Electrical Engineer, Rawhide Energy Center, Platte River Power Authority–How this power plant supplies energy to the region
- Mr. Manny Alexander, Eaton Corporation–Inner workings of EV Charging Stations

Annual Colorado Global Climate Conference
CSU, Fort Collins, CO October of 2012 and 2013
Session Attendance: 40 students, 5 teachers
In collaboration with the Center for Multiscale Modeling of Atmospheric Processes (CSU) three 40–minute information sessions were conducted for high school students about the inner workings of advanced electric vehicles. Regenerate! activity kits were used to investigate energy transfer and regenerative braking. The Center for Multiscale Modeling of Atmospheric Processes is the host of this annual conference aimed at students and teachers from across Colorado and made an excellent partner for the student activity. See Figure 18.

Figure 18: Global Climate Conference

Colorado Science Conference for Professional Development
Merchandise Mart, Denver, CO November, 2012
Attendance: 28 teachers
The conference included an interactive presentation for middle and high school teachers on how to incorporate STEM concepts in their classrooms by using the PHEV as a "vehicle" to engage students. Demonstrations using the Regenerate! kits were used as an introduction to the industry. Eight sets of kits were "raffled" off to interested teachers.

2012 Girls Exploring Science, Technology, Engineering and Math (GESTEM)
"Hybrid/Electric Vehicles–for Girls!" Colorado Convention Center, Denver, CO April, 2011; Workshop Attendance: 85 6th and 7th grade female students

Figure 19: Girls Exploring Regenerative Braking

Hosted by the Society of Women Engineers Rocky Mountain Section, three workshops for 6th and 7th grade girls from across Colorado showcased the Regenerate! Kit with an interactive demonstration about energy transfer and regenerative braking in hybrid electric vehicles (see

Figure 19). The young participants were also treated to personal interactions with women engineering college students (from the EcoCAR 2 team). Overall, 903 students attended this event. This workshop, Hybrid/Electric Vehicles for Girls! was one of 93 workshops selected for participation.

3.1.3 Community Outreach

Get Charged: Plug in to hybrid Electric Vehicles (PHEV) – This was the initial tri–fold brochure created to distribute at community events, advocating industry opportunities, careers in the field and information about the education program. The brochure was given a one–page update after the first year.

2010 Denver Metro Clean Cities Coalition/Arapahoe Community College, Odyssey National Alternative Fuel Vehicle Day; Arapahoe Community College, Littleton, CO October, 2010; Attendance: 100 consumers and students

A variety of alternative fuel vehicles were on display during this campus expo as shown in Figure 20, including those powered by compressed natural gas, propane, biofuels and electric technologies. Local organizations showcased program areas related to alternative fuels and cleaner air. The alternative fuel vehicle training program at ACC was one of the featured exhibits and several panel presentations educated attendees on technologies, safety and degree opportunities in automotive technology. Sponsors and partners included Jon Van Bogart, Scott Rill, Jerry Viola, Denver Regional Transportation District, Layton Truck, General Motors, Ferrell Gas, Regional Air Quality Council, Go Smart Technologies, Boulder Electric, the American Lung Association of Colorado and CSUV.

Figure 20: ACC Odyssey National Alternative Fuel Vehicle Day

2012 Northern Colorado Clean Cities Coalition/Aims Community College Odyssey National Alternative Fuel Vehicle Day, Aims Community College, Automotive and Technology Center, Greeley, CO October, 2012; Attendance: 75 students and consumers

This event promoted alternative fuels through a day of activities including a keynote address, three industry expert panels and a vendor and vehicle expo. CSUV–VEEP presented online educational materials about PHEV inner workings using Gooru. Sponsors/Partners**:** Aims Automotive and Technology Center, AVS, Chesapeake Energy, Colorado Corn, Eaton, FuelTek, GP Strategies, JW Power Company, Nissan and Mansfield Energy Corp (SkyBlu Smart Fuels brand).

Northern Colorado Clean Cities 15th Anniversary Event
Rocky Mountain Innosphere, Fort Collins, CO September, 2011; Attendance: 50 consumers and industry representatives
The Program presented a poster describing VEEP as depicted in Figure 21.

Figure 21: Colorado Clean Cities

Colorado Rides Electric Day, Harmony Library, Fort Collins, CO May, 2012 Attendance: 55 community members, consumers and students
This event was created to commemorate Colorado EV Day in accordance with Colorado Governor Hickenlooper's proclamation of statewide Electric Vehicle Day on May 17. The Program, teamed with the Northern Colorado Clean Cities and the Poudre River Public Library District, offered an electric vehicle expo and screening of the documentary film, "*Revenge of the Electric Car*." Images of this event are shown in Figure 22. Attendees were treated to presentations from City of Fort Collins, EcoCAR 2 and CSUV representatives. Videos, games, lectures and hands–on demonstrations about PHEVs were offered to the general public (rechargeable batteries, the Electric ride Colorado website, (http://www.electricridecolorado.com/) regenerative braking, Xbox™ CSU EcoCAR 2 game, electric vehicle tax incentives and charging stations). Free pencils, brochures and T-shirts promoting the Electric ride Colorado website were given to participants.

Figure 22: Colorado Electric Rides Day

Sustainable Living Fair
Fort Collins, CO September, 2012; Exhibit Attendance: 10
Program partnered with Northern Colorado Clean Cities and EcoCAR 2 for a slide presentation and exhibit to the about advanced electric vehicles. CSUV also partnered with Drive Electric Northern Colorado's Electrification Coalition for the 2013 Sustainable Living Exhibit booth to offer interactive demonstrations, drive and ride and poster presentations with discussion, but the two–day event was canceled due to the massive Colorado floods in September, 2013.

Osher Lifelong Learning Institute, MacKenzie Place, Fort Collins, CO September, 2012
Dr. Bradley, Dept. of Mechanical Engineering, presented a talk entitled "Plug–In Electric Cars" to Senior Scholars at this vibrant Independent and Assisted Living senior community.

BizWest Media, Bixpo 2012, Northern Colorado Business Conference, Loveland, CO; September, 2012; Attendance: Over 500 representatives from regional businesses and the community (Figure 23)

Figure 23: Bixpo Conference

Bixpo is an annual event where a hundred plus exhibitors showcase the latest business products, services and technologies, along with a variety of speakers and workshops. There is a primary focus on workforce development and job exploration. Nearly 20,000 people have gathered over the past eight seasons to share ideas, check out new business technology, listen to thought leaders and connect to do business. CSUV sponsored the event and exhibited information promoting careers and education in the automotive industry with focus on courses offered in Systems Engineering and Engineering Management. Dr. Gary Caille gave a presentation on STEM education and business partnerships during the Business Leaders Luncheon at this event. An accompanying article in Northern Colorado Business Report was published, "*CSU Ventures – "Moving PHEV Technology and Education Forward*" (Caille, Bradley & Smeraski).

NetZero Cities, Fort Collins Hilton, (two day symposium) October, 2012
Attendance: 400 industry members, consumers, teachers, students and faculty
This was the first annual symposium for community members, educators, businesses, government and political leaders across Colorado and the globe to learn, share and advance real–world paths that can be taken to attain "net–zero" energy, carbon and waste communities world–wide. Mr. Jacob Ward of DOE's Vehicle Technology Office spoke on DOE PHEV programs and the vision forward. CSU Ventures representatives partnered in planning the symposium, including sessions with both local and international speakers:
Session 1: *Technologies and Innovations* (Emerging Innovative systems and Technologies)
Session 2: *World Applications* (Implementation Strategies)
Session 3: *Education and Mentorship* (Education Systems and STEM for the Millennial Generation)
Session 4: Policy, Financial Systems, Cultural Engagement.
Particular attention was focused on the development of Session 3, "Education and Mentorship." The objective was to bring together industry and educators in the fields of energy, environment and transportation to begin connecting on common issues of workforce development. Roundtable discussions with the audience, speakers and panelists were held to improve networking opportunities following panel discussions. Panelists for Session 3 were made up of internationally diverse representatives from higher education, community colleges, elementary, middle and high school administrators. The conference lectures and panel discussions were captured and broadcast on City of Fort Collins Cable Channel 14 for several months following the conference.

A subset of the conference presentations remain archived on City of Fort Collins Cable Channel 14:
City at a Glance–Intro to 2012 Net Zero Cities Conference (9/29/12)
http://www.youtube.com/watch?v=4DXCZ9QNhnQ
Policy, Finance and Culture with Bill Ritter
http://www.fcgov.com/youtube.php?vid=z5lG3P4WBjg&list=UU9yI7q_1fhS4KpfQp74mokQ
Mentoring for the New InnoTech Workplace with Bret Lessman
http://www.fcgov.com/youtube.php?vid=u2GlVcWlikQ&list=UU9yI7q_1fhS4KpfQp74mokQ
eTown Hall with Nick Forster
http://www.fcgov.com/youtube.php?vid=Tfe1ItGpsCI&list=UU9yI7q_1fhS4KpfQp74mokQ
Taxi of Tomorrow with David Klahr
http://www.fcgov.com/youtube.php?vid=DBDX3y2boWk&list=UU9yI7q_1fhS4KpfQp74mokQ

Drive Electric Northern Colorado (DENC)–Electrification Coalition; Fort Collins Museum of Discovery, Fort Collins, February, 2013; Attendance: 125 community members
The Program assisted DENC in their press conference and "drive and ride" kick–off campaign to advocate EVs in the City of Fort Collins and to break ground for the community EV Charging Station at this new local science museum (Figure 24). EcoCAR 2 students and CSUV representatives were available to answer questions and recruit teachers in the community for outreach events at their schools.

Figure 24: Drive Electric

E3 Conference (Electrifying the Economy–Educating the Workforce) Dearborn, Michigan, June 2013
Dr. Gary Caille participated as a panelist for "Educational Programs on Transportation Electrification: Current Status and Future Needs" The panel discussed the status of programs and courses developed with support by the Department of Energy for the advancement of electric drive vehicle engineering educational programs. Panelists discussed recent progress of their programs, including enrollment and student demand, student placement and employment, student survey results and other outcome measures. They also assessed the need for additional courses and curricular changes in the area of transportation electrification.

3.1.4 Outreach to Native Americans, Veterans and Women

CSUV undertook efforts to market to and effectively recruit under–represented populations (Native Americans, veterans and women) into PHEV training programs at ACC and CSU's Mechanical Engineering program.

Based on the findings from focus groups conducted by CSUV in February, 2012, individuals from each of the target populations were identified and recruited to serve as spokespersons to be active both personally at live events and in online media. Spokespersons were chosen to be representative of their population and to be proponents in the broader field of sustainable energy technologies. Spokespersons were actively engaged in their communities and of course, were chosen for their ability to be outgoing and approachable. Four spokespersons were recruited and represented the project online and in person throughout the last year of the project.

In addition to online approaches discussed this Subtask, CSUV coordinated ACC car care clinics for the target populations and tied these activities directly to online community building through social media channels.

3.1.5 Personal Outreach Events – Networking

Personal engagement was emphasized throughout the program and core materials were naturally more effective when coupled with personal outreach. Key events program representatives attended included:

- In 2012
  - Aurora Chamber of Commerce Air Force Recognition Luncheon
  - Women Veterans of Colorado Resource
  - CSBR/National Defense Industry Association Networking Event
  - Buckley Air Force Base Annual Career and Education Fair (co–presence with ACC)
  - Bo Matthews Center of Excellence/Community Referral and Resource Center Grand Opening
  - Denver Metro Small Business Development Center Veteran Outreach Event
  - US Chamber of Commerce Boots to Suits Job and Education Fair
  - Denver Indian Center (DIC) Pow–Wow
  - Fort Carson Inaugural Post Graduation

- In 2013
  - Military Veteran Employment/Education Expo (in partnership with the US Chamber of Commerce)
  - DIC Career and Education Network Event
  - 39th Annual Denver March Pow–Wow
  - 29th National Space Symposium (with The Space Foundation)
  - Military Veteran Employment/Education Expo.

3.1.6 Personal Outreach Events – Car Care Clinics

A key recommendation to come out of the 2012 focus groups was the recommendation to hold events that would directly expose target populations to alternative fuel vehicles. This held true for career–stage adults as well as secondary school students. For the career–stage adults, the goal was to expose people to the field in an informative, casual and interactive environment at ACC. By both giving them valuable information and skills in a comfortable format, participants had the opportunity to see that an automotive field was something they could actually consider.

The clinics were kept simple and each one specifically targeted to each selected demographic separately. Email invitations were sent out where possible and collateral was generated (usually posters or handouts) for each clinic. Event postings were made regularly on each Facebook page leading up to the event and spokespersons and partner organizations were engaged for promotion where possible. By the end of the contract, one car clinic was held at ACC's Automotive Technology Department for each of the demographic groups.

Women's Car Care Clinic
Recruiting partner: Project WISE, Denver; Arapahoe Community College, Littleton, CO ***Instructor:*** *Jerry Viola, Automotive Technology Department Director*
Collateral and placement: Posters and flyers were distributed and the event promoted through the "Women Get Technical" Facebook site and on Project WISE's website.

All attendees received gift bags with practical and promotional items. See Figure 25.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Nonprofit helps women fine tune their job skills

By Laura Gabbay
YourHub Contributor

On Feb. 23, Project WISE, a Denver-based nonprofit committed to the empowerment of women facing economic challenges, hosted a women-only clinic on the ins and outs of cars.

The workshop was taught by industry professionals from Arapahoe Community Colleges Automotive Technology program, including Jerry Viola, the director of the program at the college.

The five women who participated in the inaugural Women Get Technical workshop learned all the basics to keep a car running smoothly, including changing a tire, checking the fluids, lights and fuses, and much more. Along with basic car anatomy, the women were able to ask questions that people never get to ask at the shop. The event was free to all of the participants and included lunch donated by Arapahoe Community College.

Project WISE provides resources to women of low incomes to help in the achievement of economic self-sufficiency. The organization's job coaching services increase an individuals ability to develop career and life skills essential to improving self-confidence, strengthening support systems and improving the interpersonal skills needed to achieve long-term employment.

The aim of piloting this particular workshop was to introduce women with low incomes to non-traditional, career-oriented jobs, such as automotive technicians.

Established in 1995, Project WISE, which stands for a Womens Initiative for Service and Empowerment, was created to address the personal and economic barriers to financial stability among women with low incomes and women receiving welfare or temporary assistance. Listening to women's experiences of previous welfare reform legislation, founders developed the programs of Project WISE to address the needs of low-income women in employment readiness, educational advancement, life skills, and family and community leadership. Last year, Project WISE served 225 women living at or below 200 percent of the federal poverty level.

"It really is rocket science," Viola said, speaking about automotive technology, after explaining that there are at least 50 computers onboard any given contemporary automobile.

"Just give me dedicated, enthusiastic people who really want to work, and I will help them and get them through this program," he said.

The next free Women's Leadership Program workshop of Project WISE will be held at 5:30 p.m. March 14 at the organization's office, 1301 Kalamath St. The March workshop, "From Diploma to Degree: Stories of Women Going Back to School" is open to all women facing economic challenges. To make a reservation, call 303-765-5879 or visit denverprojectwise.org.

Laura Gabbay is the executive director at Project WISE.

Project WISE workshop participants learn what's under the hood with Jerry Viola. *Photo by Mary Callan*

Figure 25: Women's Car Care Clinic photo and Denver Post, Article March 7, 2013

Denver Indian Center Car Care Clinic
Recruiting partner: *Denver Indian Center and Native spokespersons;* ***Instructor:*** *Cardell Webster, Arapahoe Community College Automotive Technology Instructor*
Collateral and placement: Posters and flyers were distributed and placed at ACC and the DIC and the event promoted through the "Native Talent and Technology" Facebook site and on the DIC's website. Images are shown in Figure 26. E–mail marketing was also used prior to the event, with branded emails with the same look, feel and messaging. Complementary gifts were given to attendees as well.

Figure 26: Denver Indian Center Car Care Clinic

Veterans Car Care Clinic
Recruiting partner: *ACC Veterans Certifying Official, Nancy Nickless*
Instructor: *Cardell Webster, Arapahoe Community College instructor*
Collateral and placement: Posters and flyers were distributed and placed at ACC and online and collateral was distributed at several veterans' events prior to the clinic. The event was also posted on the "Vets Get Technical" Facebook site and through Eventbrite website and email marketing. At all events the team was accompanied by large and striking banners that were generated as part of the project, all with messaging consistent with online material.

3.1.7 Broader Impact and Sustainability of Program Task

- Retaining spokespersons to connect with target populations is highly effective. It is recommended that spokespersons for recruiting efforts be retained that are closely aligned with the target demographic <u>and</u> closely aligned or engaged with the educational institution of choice.
- Spokespersons are best engaged for an extended period of time (minimum of 12 months, preferably longer) to truly allow for the target population to identify them with the program, the industry and the communication channels in which they are used. This is particularly crucial when reaching out to cultures that are tight–knit and ethnically cohesive, such as the Native American population.
- Schedule regular, consistent and engaging events to draw candidates to the institution and provide something of tangible value to the participants (beyond information sharing around a table).
- Though the effectiveness of mobile apps for outreach and recruitment remains to be seen, an extended period of implementation time should be allowed to fully gauge the value of the investment.
- For populations that are particularly cohesive among those of their own ethnicity or demographic, it is advised that an ongoing presence be established at locations where they socialize and learn with one another (e.g., the DIC being an important location for Native Americans). Demonstrating a welcoming, informative and trustworthy presence where potential students and program participants can get answers to enrollment and financial questions is vital to outreach success.
- For these same populations, creating a place of refuge, affiliation and support on campus where they can meet among themselves and also receive guidance is highly recommended.

Challenges and Obstacles

- The program did not get traction in promotion to women as a specific target group. In reviewing the project, it was concluded that compared to other target demographics, women were much less defined as a population; there was no specific “culture” to embrace or relate to (e.g., with Native Americans). Moreover, there was not a shared experience or common set of needs to bind them (e.g., with veterans). However, success with the education program to connect to female students at the middle or high school level was more easily attained.
- Though effective in keeping the program out in front of certain populations, particularly veterans, exhibiting and hosting tables at education and employment expos was only marginally effective.
- The use of interactive car care clinics is highly recommended across all target populations as an excellent introduction to the field and to the educational institutions. The clinic approach can greatly augment career and job fairs targeted toward each population.

3.2 Technical Training Key Project Activities

3.2.1 Automotive Coursework

Arapahoe Community College

Douglas County School District's Ponderosa High School (PHS) Automotive Tech program now features a NATEF–certified auto shop where high school students can earn college credit toward an Associate's degree at ACC and also log hours towards their ASE certification. The courses offered are available not only to students attending PHS, but also to students from all 15 high schools in the Douglas County School District through the District's Career and Technical Education Program (CTE). This includes students at the District's neighborhood, charter and alternative high schools. Students in five neighboring school districts in the Metro–Denver area are also eligible to enroll in the PHS Automotive Technology program through the District's collaboration for CTE course offerings.

Figure 27: ACC PHEV Training Poster

By earning NATEF certification, the PHS Auto Tech program is now eligible to offer concurrent enrollment credit with ACC. An agreement was formalized with ACC and this opportunity is promoted to students district–wide. Tuition at ACC is covered by the Douglas County School District and the State of Colorado's "College Opportunities Fund." A total of 57 students obtained concurrent enrollment benefits in Automotive Technology during the duration of the grant. This includes the 2011–12 and 2012–13 school years, as NATEF certification was not finalized in time for the 2010–11 school year.

ACC also developed two 2–day Safe PHEV Service and Repair instructional modules and integrated them into ACC's academic automotive program. Activities were focused on delivering a variety of training and education programs and modules using several marketing approaches in an attempt to accelerate the market introduction and PHEV penetration in Colorado. Overall enrollment numbers were low, but those who did participate evaluated the programs favorably.

ACC made its Advanced Automotive Center available to conduct both project–based academic and workforce development training programs. ACC initially purchased six PHEVs, several tool chests, software service and repair program manuals and diagnostic equipment used to service and repair the acquired vehicles throughout the course offerings. For the last two years of the contract, ACC acquired a Nissan Leaf and a Chevrolet Volt, a charging station and appropriate servicing and diagnostic equipment to augment ACC's ongoing PHEV/EV program and enhance the appeal and impact of the PHEV/EV workforce development program.

ACC participated actively throughout the granting period in promoting the enhanced automotive technology program to under–represented populations targeted in the project, including car care clinics on–site for Native Americans, veterans and women.

ACC's PHEV safe service and repair courses were continually updated throughout the course of the project. By the final grant year, three new modules were developed:

- **Module 1, Hybrid Safety and Theory–**The hybrid vehicle theory of operation, safe operation and repair of both domestic and foreign hybrid electric vehicles
- **Module 2, Plug–In Hybrid Conversion–**Focus on battery technology, vehicle–to–grid technologies and vehicle conversions (lab section included actual conversion of an HEV to a PHEV)
- **Module 3, Diagnostics and Troubleshooting of Advanced Technology Vehicles–** Instruction on the use of scan tools, wiring diagrams, trouble codes, diagnosis and controller area network (CAN) bus communications.

3.2.2 EMS/Law Enforcement Coursework

Multimedia based training and education modules were developed by ACC that were specifically tailored to various first responder program participants. These instructional modules were presented in a variety of settings both in academic and workforce development training programs over a two–year period.

The training modules achieved significant impact; evaluations received from participants showed that the program modules were useful and engaging. The hands–on approach taken was particularly appreciated and valued by participants. Three 2–day PHEV instructional modules were also developed by ACC Automotive Technology Center faculty and were marketed to ASA Colorado member automotive technicians using a variety of marketing approaches.

However, it became clear to all those involved in this project that although the quality of instructional offerings were excellent, these education and training programs were ahead of the demand–curve in the Colorado marketplace. Since most PHEV/EVs are inherently well designed with numerous built–in safety features, most public service and automotive professionals perceive the threat to first responders and automotive technicians as very low. Because of this, both ACC and RRCC experienced very low participation rates in most of the courses offered through the two year offering period. There were some notable exceptions where attendance was high: where participants clearly had a "need to know," the knowledge and skills being presented, classes enjoyed high enrollment.

Nearly three hundred students participated in academic programs at ACC and RRCC conducted under the grant. Equally important, however, is the impact this program had on the student educational experience in the ACC automotive academic programs and the RRCC fire academy programs. Students in these programs benefited greatly from the opportunity to work on the latest PHEVs/EVs with the most current and most sophisticated high technology tools and instructional modules. Students also greatly benefited from top–notch instructors who taught them how to work safely on and around these vehicles in their shops and in accident situations.

The project involved the collaboration of several higher education institutions in Colorado, (CSU–ME, ACC, RRCC) with organizations such as the NFPA, National Highway Administration (NHA), a variety of Original Equipment Manufacturers (OEM), Denver Metro Colorado Clean Cities Coalition, Northern Colorado Clean Cities Coalition, the American Lung Association's Electric Ride Program and Veterans Green Jobs to create partnerships that made use of public and private funds to foster the safe servicing and repair of PHEV/EV while enhancing the environment in Colorado and opening up new career possibilities for Native Americans, veterans and women.

The project enhanced the capacity and capability of ACC and RRCC to provide state–of–the–art automotive, EMT, law enforcement and first responder PHEV/EV safety training and education for practicing professionals and students in academic programs at both institutions.

3.2.3 Virtual Reality

The goal of the virtual reality (VR) technology task was to develop a step–in motion capture system that would assist technicians in performing key maintenance procedures using Head Mounted Displays (HMD). As an initial activity in the task, Motion Reality Inc. (MRI) developed and delivered an interactive animation of the battery isolation procedure for the Toyota Prius, including safety precaution and OEM safety procedures. After reviewing this initial animation, the VR effort was suspended after delivery of the first animation for the following reasons:

- The virtual reality equipment (HMD) and projection equipment remain specialized and the cost would be too high for most dealers or trainers.
- The rising quality of video capture for instructional purposes (with economical HD cameras) has made the VR methodology non–competitive due to significantly higher production costs.
- Updating or modifying VR procedures would take significant time and cost relative to video capture technologies.
- Though the interactive nature of the VR technology is an advantage over traditional instruction, this advantage is easily offset by direct instructor supervision.
- The OEMs were not receptive to new training modalities; they mandate the use of their own brand–specific training programs, primarily because of liability concerns.

ACC's credit and certificate programs developed under this grant resulted in highly sustainable impacts:

- Approximately 300 student professionals participated in academic courses in preparation for careers involving the safe accident response, repair and service of hybrid advanced technology vehicles.
- More than 220 workforce professional – firefighters, law enforcement officers, EMTs and independent service/repair providers participated in the training programs developed under the grant.
- The development of multimedia based training and education modules that were specifically

tailored to various first responder program participants will continue to be used by professionals and serve useful for them to evangelize others in the value of such training.

- Significant public/private partnerships were formed that are sustainable in accelerating the market introduction and PHEV penetration in Colorado.
- The technical effectiveness of this method of workforce development was testified to many times over in the program evaluations received by participating first responder and automotive service/repair professionals. Even high school and middle school STEM teachers who participated in workshops conducted on the CSU campus in Fort Collins (supported by ACC instructors and ACC's EVs) stated that they experienced great value from interactive demonstrations.
- The project provided effective use of ARRA funds in providing jobs during the recovery period and enhancing the future career opportunities for students, first responders and automotive service professionals who choose to work with PHEV/EVs. Continued use of newly acquired hybrid vehicles under the grant will provide years of highly relevant training for automotive technology students.

3.3 University Level Education Key Project Activities

The needs assessment, "From course assessment to redesign: a hybrid–vehicle course as a case illustration," was utilized to structure course objectives and to define outcomes for students and their potential employers. CSU conducted 17 industry interviews, nine of which were used to supplement course content. Core course content was aligned with and supported by Subject Matter Experts review. Please see also "From course assessment to redesign: a hybrid–vehicle course as a case illustration" (**Publications, Papers and Conference Proceedings**, Stanton and Bradley, 2013).

At the undergraduate and graduate level, CSU and Georgia Tech collaborated on the development of six new courses. Course materials were developed as a collaborative effort, leveraging subject matter experts at both schools. Graduate students assisted with development of simulation–based design tools. Efforts were initiated at the start of the grant period to establish protocols for co–offering the courses such that any course can be taught at one physical location while attended by students at both institutions. This effort leveraged distance learning classrooms and infrastructure (video capture and digitization equipment, web portals, etc.) present at both schools. The primary training needs for electrified vehicle engineers are to develop multidisciplinary engineering graduates with in depth knowledge of: 1) Automotive engineering with EV/PHEV/PHEV applications, 2) Systems engineering in the application, 3) Electrical energy generation, storage and conversion and 4) Economic and policy considerations in the application. Table 2 shows how the CSU/Georgia Tech curriculum has addressed these educational needs as a function of project phase with new and ported courses. Table 3 shows the number of times each course was instructed and number of students enrolled in each section for all courses taught at CSU.

Table 2: University Training Objectives		
University Level EV/PHEV/PHEV Engineering Training Needs	Phase 1 (Y1)	Phase
Automotive Engineering with EV/PHEV/PHEV Applications	Georgia Tech – PHEV Powertrains Course	CSU Advanced Engines Course
	Georgia Tech– PHEV Short Course	
Systems Engineering with EV/PHEV/PHEV Applications		CSU – EV/PHEV/PHRV Systems Design Course
		Georgia Tech – PHEV Simulation Based Design Course
		Georgia Tech – Control in PHEV Systems Course
Electrical Energy Generation, Storage and Conversion	CSU – Energy Storage System Course	CSU – Transportation Electrification Course
EV/PHEV/PHEV Economics and Policy		CSU – EV/PHEV/PHEV Policy Short Course
		CSU – EV/PHEV/PHEV Economics short Course

Table 3: CSU University Training Results				
Year	**Semester**	**Course No. Title**	**Cr. Hrs.**	**Enrollment**
2011	Spring	ENGR 580–A3 Hybrid Electric Vehicle Powertrains	3	24
2011	Fall	MECH 680–A4 Transportation Electrification	3	6
2011	Fall	MECH 523 Design of Vehicle Energy Storage Systems	3	15
2012	Spring	ENGR 580–A3 Hybrid Electric Vehicle Powertrains	3	17
2012	Spring	ME 8813 Simulation Design of Hybrid Electric Vehicles	3	10
2012	Fall	MECH 527 Hybrid Electric Vehicle Powertrains	3	10
2012	Fall	MECH 580 EV/HEV Computational System Design	3	8
2012	Fall	ECE 8803 Dynamics and Control of Hybrid Electric Vehicles	3	37
2013	Fall	MECH 680–A4 Transportation Electrification	3	8
2013	Fall	ENGR 580–A1 Hybrid Electric Vehicle Powertrains	3	30
2013	Fall	ECE 8803 Dynamics and Control of Hybrid Electric Vehicles	3	32

3.3.1 Phase I – Colorado State University Contributions

Porting of PHEV Powertrains Course to CSUV Vehicle Electrification Project

ENGR 580–A1 Hybrid Electric Vehicle Powertrains, College of Engineering, CSU (S–11, S–12) This course was developed by Dr. Thomas Bradley, Dr. Ken Stanton at CSU and Dr. Mike Leamy at the Georgia Tech under contract to US DOE. S–11, 20 enrolled; Bradley 10/10. Instructor: Dr. Thomas Bradley

In the first phase of the grant work, the PHEV Powertrains course was ported to CSU for immediate incorporation into the curriculum. Porting was accomplished by providing CSU instructors with a complete and thorough set of course notes, a set of materials for a tutorial–based simulation–based design of a series hybrid vehicle, a complete set of problem sets with solutions and miscellaneous slides and audio–visual demonstrations for in–class use. The simulation–based design material is a comprehensive set of ten self–guided tutorials that lead students through the virtual build of a series architecture PHEV using the Mathworks suite of tools (Matlab, Simulink, Simscape, SimDriveline, etc.). This material was originally obtained by Georgia Tech from the Mathworks and Rose–Hulman Institute of Technology and represents a state–of–the–art instructional tool. This course was entitled ENGR 580–A3 and then MECH

527. The syllabus for this course is provided in Figure 28.

Colorado State University Course Outline

ENGR 580A1 – Hybrid Electric Vehicle Powertrains
Course Syllabus and Policies

Credits: 3 **Term:** Spring 2011 **Prerequisite(s):** *MECH 307* (Mechatronics)

Course Description:
The purpose of this course is to introduce students to the engineering design and analysis of hybrid-electric vehicle (HEV) powertrains. Internal combustion engines have been the prime mover of choice in automobiles for over a century. Increasingly stringent limits on emissions, as well as attention to conservation of hydrocarbon fuels is driving the development of alternative power sources for vehicles, with hybrid-electric powered vehicles rapidly developing as a viable solution. The course is interdisciplinary between ME and ECE – a natural consequence of the technological integration of electrical and mechanical systems inherent in hybrid powertrains; however, students are not expected to have expertise in electrical systems.

Instructors:
Thomas H. Bradley, Assistant Professor, Dept. of Mechanical Engineering, Engineering Building A103R, Thomas.Bradley@colostate.edu, Phone +1 970-491-3539
Ken C. Stanton, Post-Doctoral Fellow, Dept. of Mechanical Engineering, Motorsport Engineering Research Center 109, Ken.Stanton@colostate.edu, Phone +1 970-491-8109
NOTE: Contacts are listed in the order of preference: email, office hours, office phone. Contact via personal (non-academic) media is not permitted, such as instructors' cell phones or place of residence, without prior permission.

Webpage:
For this course, we will primarily use RamCT for giving assignments and providing course materials. Please ensure that you can log into RamCT and view the course page, and report any problems immediately.

Text(s):
[Required reading material will be made available via RamCT.]
M. Ehsani, Y. Gao, S.E. Gay and A. Emadi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*, CRC Press, 2005.
Electric and Hybrid Vehicles: Power Sources, Models, Sustainability, Infrastructure and the Market (2010). Elsevier Science Ltd.

Course Objective(s):
After completing this course, the student will be able to:
1. Concisely explain background, strengths, and weaknesses of various vehicle powertrains
2. Identify and describe HEV powertrain configurations
3. Calculate parameters of HEV powertrains for static and dynamic conditions
4. Evaluate design tradeoffs for basic HEV powertrain concepts
5. Construct and simulate models with consideration for basic aspects of HEV vehicle dynamics, IC engine, electric motor, energy storage, control system, and regenerative braking
6. Methodically design and simulate an HEV with consideration for basic aspects of HEV vehicle dynamics, IC engine, electric motor, energy storage, control system, and regenerative braking

Course Topics/Weekly Schedule:
1. Introduction to hybrid-electric vehicle powertrains (0.5 weeks)
   a. Brief history and motivation for development of HEVs
   b. Basic design fundamentals to improve fuel efficiency
   c. Mild and strong categorization
   d. Series, parallel, and planetary-coupled configurations
2. Fundamental vehicle dynamics (1 week)
   a. Road load: rolling resistance, aerodynamic drag and gravitational load
   b. Traction force: tire-road adhesion, characteristics of power plant and transmission
   c. Vehicle performance: maximum speed, gradeability and acceleration
   d. Effect of vehicle design on fuel consumption
3. Internal combustion engines (3 weeks)
   a. Operating principles
   b. Fuel consumption, efficiency and emissions
   c. Brake power and torque
   d. Techniques to improve performance, efficiency, and emission characteristics
4. Electric propulsion systems and electric vehicles (2.5 weeks)
   a. DC motor drives: principles of operation and performance
   b. AC induction motor drives: principles of operation and performance
   c. AC synchronous motor drives: principles of operation and performance
   d. Electric vehicle configurations and performance
5. Energy storage (3 weeks)
   a. Electrochemical batteries: power, energy, efficiency and technologies
   b. Ultracapacitors: basic principles and performance
   c. Flywheels: basic principles and performance
   d. Hybrid energy storage strategies
6. Regenerative braking (2 weeks)
   a. Energy consumption in braking at front/rear wheels
   b. Energy recovery techniques
   c. EV and HEV regenerative braking schemes
7. Design, performance and control in HEV powertrains (3 weeks)
   a. Overview of strategies: performance, cost and complexity
   b. Series HEV drivetrain design, control, and performance
   c. Parallel HEV drivetrain design, control, and performance
   d. Mild HEV drivetrain design, control, and performance
8. Group Project Presentations [in lieu of final examination] (1 week)

Instructional Methodology and Mode of Delivery:
This course will be presented in lecture format using mixed media to present content and examples. Lectures will 50 minutes long, three days per week; for five weeks of the semester, class will meet at the computer lab for modeling and simulation activities. Homework problems will typically be assigned every other week (due one week later). Students are expected to work on all these problems yourself (or within your team), but *reasonable* collaboration is allowed. In addition, there will be a computer-based team project.

Figure 28: ENGR 580A/MECH 527 PHEV Powertrains

The summary of student evaluations for this course is present in the Teaching and student feedback results:

- Summary – **Exams need to be revised:** "First exam was slightly ridiculous." **Book choice needs to be revised:** "A better book would be helpful for those who are more visual learners." **Course is well developed:** "Freaking awesome class. This was by far one of the best and most comprehensive courses that I have taken at CSU."

  Responses – In response, a rigorous course update was performed. The course was revised to incorporate the ideas of project–based learning. The emphases of lectures and laboratories were aligned with a semester long project on modeling and analyzing hybrid electric vehicles in MATLAB. Ideally, this provides some more structure to the course and better integrates the computer laboratories into the course. Please see the section on Examples of Course Improvements for more detail.

For the second course17 students enrolled. A student evaluation of Dr. Bradley from 10/10 follows:

- Summary – **Need to provide more introductory information or refine prerequisites:** "Learning MATLAB/Simulink were challenging, but it will give me a competitive edge," "class was challenging" **Provide more case studies:** "I wish for more classes about hybrids in general." **Book choice needs to be revised:** "I recommend a new text." **Course is well developed:** "Great course, especially the modeling portion," Porting of Vehicle Energy Storage System Design Course to CSUV Vehicle Electrification Project

As part of Phase I, CSU revised and applied a pre–existing course (entitled *Vehicle Energy Storage System Design)* to the university education program. This course provides an introduction to the fundamentals of battery and fuel cell electrochemistry, thermodynamics and materials with applications in electric transportation.

The CSU *Vehicle Energy Storage System Design* course provides an introduction to the foundations of energy storage in electrified vehicles including hybrid electric, fuel cell and PHEVs. The fundamental concepts of materials, electrochemistry and thermodynamics are connected to the application of electrified transportation through a series of system engineering modules. These modules describe the methods for design of energy storage systems in the mobile application including battery pack specification and design, battery state of charge monitoring, fuel cell balance of plant design, etc.

This course was developed out of an experimental course and became MECH 523, Vehicle Energy Storage System Design, a component of the CSU/Georgia Tech Vehicle Electrification Project. The syllabus for this course is provided in Figure 29.

- **Instructor,** MECH 523 *Design of Energy Storage Systems for Vehicles*, College of Engineering, CSU (F–11). This course was developed by Dr. Bradley under contract to US DOE. It is completely new for F–11 semester. The course involved five laboratory sections wherein students 1) construct galvanic couples, 2) measure fuel cell performance, 3) describe automotive battery pack systems, 4) measure battery performance and 5) measure ultra–capacitor performance. F–11, 13 enrolled, student evaluations were not gathered.

Colorado State University Course Syllabus
MECH 523 – Vehicle Energy Storage System Design

Instructors:
Thomas H. Bradley, Assistant Professor, Department of Mechanical Engineering, Engineering Building A103R, thomas.bradley@colostate.edu, Phone: +1 970-491-3539

Meeting Time:
Engineering D 102, 9:00 am - 9:50 am, WMF
University Holiday is Monday September 5th
PLI Day is Friday, November 4th

Texts:
Bagosky, V.S. Fundamentals of Electrochemistry, 2nd Ed. 2006 (available online at lib.colostate.edu)
Huggins, R.A., Advanced Batteries, Springer, ISBN 978-0-387-76423-8
EG&G Services, Parsons, Inc., and Science Applications International Corporation, Fuel Cell Handbook, 5th Ed. US Department of Energy, Morgantown, West Virginia, 2000.

Prerequisites: ME 331, ME 536

Office Hours: TBD

Instructional Methodology/Mode of Delivery:
This course will consist of 3 five-week modules. Each module will introduce and analyze one technology for electrochemical energy storage. For the first half of each module, Prof. Bradley will provide a detailed introduction to the technology from an electrochemical, thermal, and materials perspective. For the second half of each module, Prof. Bradley will provide a systems-level introduction to relevant applications, sustainability impacts, powerplant design, and application level optimization.

This course will be presented in lecture format using mixed media to present content and examples.

Homework problems will usually be assigned every Friday (due one week later). In addition there will be a number of special computer-based projects at the end of each module. Students are expected to work on all these problems yourself (or within your team), but *reasonable* collaboration is allowed.

Grading and Exams:

Midterm Exam	20%
Final Exam	30%
Computer Projects	30%
Homework Assignments	20%

Course Description:
Electrochemical energy storage systems are a key component for improving the sustainability and effectiveness of every economic and energy sector. This course connects the fundamental knowledge of electrochemistry, thermodynamics and materials to systems-level analysis of important energy storage applications, including mobile powerplant design, electrified transportation, and hybrid systems.

Student Learning Objectives:
1) For primary battery chemistries, analyze the performance of the electrochemical cell using the tools of undergraduate curriculum, including thermodynamics, materials, and heat transfer.
2) Based on these analyses, construct system-level design and simulation tools that can capture the tradeoffs central to battery system utilization and in-practice engineering.
3) For the primary fuel cell technologies, analyze the performance of the electrochemical cell using the tools of undergraduate curriculum, including thermodynamics, materials, and heat transfer.
4) Based on these analyses, construct system-level design and simulation tools that can simulate the performance of the fuel cell as a component in a powerplant and vehicle system.
5) Analyze the performance of the ultra-capacitor cell using the tools of undergraduate curriculum, including thermodynamics, materials, and heat transfer.
6) Combine the simulation tools developed in the previous modules to complete a hybrid fuel cell/battery/u-cap system model that can be sized and optimized for cost and performance objectives.

Course Schedule:
Module 1 – Battery Systems
Week 1 - Introduction, Fundamentals, Principles determining voltages and capacities in electrochemical cells, Thermodynamics of electrochemistry
Week 2 - Battery basics - Components, Terminologies, Cell-level design options
Week 3 - Materials aspects of batteries - Cathodes, Anodes, Electrolyte - background history, development of Li-ion battery, Technical Challenges
Week 4 - Design issues associated with large-scale batteries, pack design, SOC measurement, thermal management.
Week 5 - Design considerations for battery electric vehicles
Module 2 – Fuel Cell Systems
Week 6 - Fuel Cell Basics (Thermodynamics, Concepts)
Week 7 - Fuel Cell Performance
Week 8 – Types of Fuel Cell Systems (PEM, SOFC, Direct Methanol)
Week 9 - System Design Considerations (Focused on Balance of Plant Engineering)
Week 10 - System Design Considerations (Vehicle Design, Hydrogen Storage)
Module 3 – "Ultracapacitor" Systems
Week 11 – Ultracapacitor Basics
Week 12 – Ultracapacitor Materials and Architectures
Week 13 – Hybrid Capacitor/Battery Systems
Week 14 – Vehicle Simulation and Design
Week 15 - Overall course summary, Introduction to future technologies

Figure 29: Syllabus for MECH 523 Vehicle Energy Storage System Design

3.3.2 Phase II – Colorado State University Contributions

CSU designed and implemented two additional courses in the Mechanical Engineering department.

New Course 3: MECH 680 Transportation Electrification

This course seeks to understand the energy connection between the electrical grid as well as personal and public transportation needs. This understanding requires knowledge of the technical, economic, policy and consumer behavioral aspects of the grid and of personal transportation. Within these contexts, this course will present the tools and techniques for interfacing vehicles to the electrical grid, for quantifying their costs and benefits to the electrical system operators and for analyzing the commercialization of transportation electrification technologies.

This course is presented for three days of the week in lecture format using mixed media to present content and examples. Mondays is an instructor–directed discussion section that discusses the homework to be completed by the next Monday. The discussion addresses the methods for analysis and solution of the homework problems.

The course has a three–week final project which allows the student to evaluate a transportation technology in detail. These final projects include synthesis and analysis of vehicle technologies, cost models, environmental impacts and more.

The syllabus for this course is provided in Figure 30. The summary of student evaluations is present in Table 4.

Colorado State University Course Syllabus
MECH 680 – Transportation Electrification

Instructors:
Thomas H. Bradley, Assistant Professor, Department of Mechanical Engineering, Engineering Building A103R, Thomas.Bradley@colostate.edu, Phone: +1 970-491-3539

Texts:
A collection of relevant reading material including excerpts from:
1. Blume, SW, Electric Power System Basics for the Nonelectrical Professional, IEEE, 2007.
2. Electric Power Research Institute. *Comparing the benefits and impacts of hybrid electric vehicle options*, Palo Alto, CA, 1000349; 2001.
3. Hughes, A, Electric Motors and Drives, Second Edition, Newnes 1993.
4. Wang, M, et al. GREET 1.8b, Argonne National Laboratories, 2009.
5. Bagosky, V.S. Fundamentals of Electrochemistry, 2nd Ed. 2006 (available online at lib.colostate.edu)

I will provide handouts of the relevant chapters and reports.

Prerequisites: Graduate Standing

Office Hours: TBD

Instructional Methodology/Mode of Delivery:
This course will be presented for two days of the week in lecture format using mixed media to present content and examples. Approximately semi-weekly, a discussion will address the methods for analysis and solution of the homework problems.
The course will have a 3 week final project which will allow the student to evaluate a transportation technology in detail. These final projects could include analysis and comparison of fuel cell vehicles, electric vehicles, plug in vehicles, electric mass transportation, electric buses, etc.

Grading and Exams:

Midterm Exam	15%
Final Project	50%
Homework Assignments	35%

Course Description: This course seeks to understand the energy connection between the electrical grid and our personal and public transportation needs. This understanding requires knowledge of the technical, economic, policy, and consumer behavioral aspects of the grid and of personal transportation. Within these contexts, this course will present the tools and techniques for interfacing vehicles to the electrical grid, for quantifying their costs and benefits to the electrical system operators, and for analyzing the commercialization of transportation electrification technologies.

Student Learning Objectives:
1. Provide an introduction to the generation, distribution, storage and use of electricity in the transportation energy sector.
2. Analyze the components, function and types of electric energy devices that are currently used in electric vehicles
3. Understand how the makeup of the US electric grid is dependent on the geographical, economic, political, and social landscape of the nation.
4. Provide a methodology for well-to-wheels energy analysis for electricity as an energy source for transportation.
5. Evaluate energy pathways, vehicles, and technologies for attributes of consumer acceptability, sustainability, economics, etc.

Course Schedule:
Week 1 - Introduction
Week 2 – Electric Vehicles Introduction and Classifications
Week 3 - Electric Vehicle Modeling
Week 4 - Battery Systems
Week 5 – Charging Systems and AC Power
Week 6 – Introduction to the Electric Grid
Week 7 – The Electric Grid - Generation
Week 8 – The Electric Grid – Transmission (and Midterm Exam)
Week 9 - The Electric Grid - Distribution
Week 10 - Electricity Industry Economics
Week 11 – "Well to Wheels" Lifecycle Analysis and Marginal Generation Concepts
Week 12 – Consumer Behavior in Personal and Mass-Transportation Fields
Week 13 – Lectures to Support Final Project
Week 14 – Economics of Electric Transportation
Week 15 – Final Project Presentations
Week 16 – No Final Examination

HW Assignment List:
HW1 Reading and analyzing research literature
HW2 Modeling the time resolved charging and fueling of PHEVs
HW3 EV/HEV Modeling Comparisons (Simulink, Advisor, PSAT, Autonomie, Modelica, Excel)
HW4 Application of Transportation Statistics to modeling of EV effectiveness and costs
HW5 Full fuel cycle comparison of novel plug in vehicles (PHEV natural gas vehicles, PHEV fuel cell, neighborhood electric vehicles)
HW6 Final Project – Project proposals to be submitted by students

Figure 30: Syllabus for MECH 680 Transportation Electrification

Table 4: Teaching and student feedback results	
Instructor, MECH 680–A4 *Transportation Electrification*, College of Engineering, CSU (F–11) This course was developed by Dr. Bradley under contract to US DOE. It is completely new for F–11 semester. F–11, 7 enrolled, student evaluation of Bradley 10/10	**Summary** – "Excellent class. I hope it will be available in the future. It was a good learning experience to have a project that has real world value" "Computer screens block a good portion of the board and makes viewing difficult." "Cutting edge course with a focus on modern research and tools. Advertise this course more rigorously to increase enrollment." "More reading through semester would be cool."

3.3.3 New Course 4: EV/PHEV Computational Systems Design Course

Although the benefits of the PHEV concept have been validated through modeling and demonstration projects, the impact of vehicle design on PHEV performance is not well understood. To date, the models that have been used for PHEV design and modeling are either custom vehicle modeling programs, or else are commercially available programs such as ADVISOR, or PSAT. In general, these programs are designed for fuel economy prediction, hardware in the loop simulation and low–level powertrain modeling. The limitations of these tools have diminished the role that vehicle design studies have played in defining the characteristics of PHEV designs. For instance, the emphasis on optimization of vehicle fuel economy has excused researchers from modeling and developing the PHEV architectures that are being presently developed by automakers. Whereas nearly all simulated PHEVs have been parallel, ZEV capable PHEVs, the automakers have been developing range extending and blended mode PHEVs to meet perceived customer requirements for cost, drivability and reliability.

This course uses the modeling and design languages of Modelica and ModelCenter to perform system level studies of vehicle energy consumption, vehicle use behavior, stochastic economic costs and benefits analyses and more. This course presents these tools of modeling and optimization of PHEV energy systems, drivelines and architectures with the goals of developing the skills and techniques that will inform the next generation of innovation for PHEVs.

The summary of student evaluations is below:

Instructor, MECH 580 Computation Systems Design, College of Engineering, CSU (F–12); this course was developed by Dr. Bradley under contract to US DOE. It is completely new for F–12 semester. F–12, 9 enrolled, student evaluation of Bradley 10/10
Summary – "Keep this course, the optimization methods that are presented are extremely useful and I have not taken any other courses in which they are covered" "Excellent teacher" "Lab sessions every week really helped to reinforce lecture material, I really enjoyed the course material and working in MATLAB/ModelCenter" "This was a fascinating course. I really appreciated the time I was able to spend meeting with Dr. Bradley outside of class. This course was very challenging but was very informative." The syllabus for this course is provided in Figure 31.

Colorado State University Course Outline

MECH 580 – Hybrid Electric Vehicle Computational Systems Design

Course Outline

Credits: 3
Term: Fall 2012
Prerequisite(s): *MECH 307* (Mechatronics)
Locations: 9:00-10:00am, MW - Engineering D102; F – Engineering B205

Course Description:
Although the benefits of the plug in (PEV) and hybrid electric vehicle (HEV) concept have been validated through modeling and demonstration projects, the impact of vehicle design and control on PHEV performance is not well understood. To date, the models that have been used for PEV design and modeling are either custom vehicle modeling programs or else are commercially available programs such as ADVISOR or PSAT. In general, these programs are designed for fuel economy prediction, hardware in the loop simulation and low-level power train modeling. The limitations of these tools have diminished the role that vehicle design studies have played in defining the characteristics of PEV designs. For instance, the emphasis on optimization of vehicle fuel economy has excused researchers from modeling and developing the PEV architectures that are being presently developed by automakers. Whereas nearly all PEV design studies have used parallel, ZEV-capable PHEVs, the automakers have been developing range extending and blended-mode PHEVs to meet customer requirements for cost, driveability, and reliability.

This course will use the modeling and design languages of MATLAB and ModelCenter to perform system level studies of vehicle energy consumption, vehicle use behavior, stochastic economic costs, benefits and more. This course will present the tools of modeling and optimization of PHEV energy system, drivelines, and architectures with the goals of developing the skills and techniques that will inform innovation in multidisciplinary mechanical system design.

Instructors:
Thomas H. Bradley, Assistant Professor, Dept. of Mechanical Engineering, Engineering Building A103M, Thomas.Bradley@colostate.edu, Phone +1 970-491-3539

Text(s):
[Any required reading material will be made available via RamCT.]

Course Objective(s):
The intent of this course is for a student to:

1. Identify and describe HEV powertrain configurations, including energy management schemes
2. Evaluate design tradeoffs for HEV configurations based on simulation and design requirements for vehicle energy consumption, vehicle use behavior
3. Perform computations component-level design and energy management strategy design for HEVs

Webpage:
For this course, we will primarily use RamCT for giving assignments and providing course materials. Please ensure that you can log into RamCT and view the course page, and report any problems immediately.

Course Topics/Weekly Schedule (All dates are approximate)

1. Introduction to automotive architectures, powertrains and energy consumption (2 week)
   a. HW1 - Straight and level automobile energy consumption minimization (optimization of 1 variable) (assigned 8/24, due 8/31)
2. Introduction to Simulation and Model Based Design (1 week)
3. Optimization Methods (cost functions, constraints, gradient-based, simplex methods, genetic algorithms) (2 week)
   a. HW2 – Simple optimization examples (assigned 9/7, due 9/14)
   a. HW3 – Drive cycle shift point optimization (assigned 9/14, due 9/21)
2. Reducing Computational Costs through Surrogate Modeling (2 week)
   a. HW4 ANN and RS examples (assigned 10/5, due 10/12)
   b. HW5 HEV drive cycle modeling (assigned 10/12, due 10/17)
3. Supervisory Control System Optimization through Dynamic Programming (3 weeks)
   a. HW6 Dynamic Programming 101 (assigned 10/19, due 10/26)
   b. HW7 HEV Drive cycle DP (assigned 10/26, due 11/2)
   c. HW8 Developing heuristic controllers from DP (assigned 11/2, due 11/16)
4. Combined Optimal Component Sizing and Control
   a. Charge Depleting vs. Charge Sustaining Control (assigned 11/30, due 12/7)
5. Group Project Presentations (12/3-12/7)

Instructional Methodology and Mode of Delivery:
This course will be presented in lecture format using mixed media to present content and examples. Lectures will 50 minutes long, three days per week; on Fridays, class will meet at the Viking computer lab for modeling and simulation activities. Homework problems will typically be assigned every other week (due one week later). Students are expected to work on all these problems themselves (or within their team), but *reasonable* collaboration is allowed. In addition, there will be a computer-based team project.

Methods of Evaluation:

Grade Assignments:		Grade Weighting:	
93-100%	A	Problem Sets	50%
90-92.999%	A-	Final Project	30%
87-89.999%	B+	Test 1	10%
83-86.999%	B	Test 2	10%
80-82.999%	B-		
77-79.999%	C+		
70-76.999%	C		
60-69.999%	D		
<60%	F		

Collaboration and Cheating:
The default at Colorado State University is that no collaboration is allowed unless expressly permitted, and students are expected to abide by the Colorado State University Student Conduct Code at all times. At no time is plagiarism, sabotage, or dishonesty permitted; all references used must be cited. Collaboration is allowed on homework and classwork, but all work submitted must be that of the individual(s) submitting said work. The final project is a team collaboration, and inter-team collaboration is allowed so long as both teams agree to it. Tests are individual work, only, and no collaboration is permitted. Violation of academic ethics may result in a zero on an assignment, negative points on an assignment, a zero for the course, or other consequences determined by the instructor based on the violation. Note: "assignment" is meant here to include all graded aspects of this course including but not limited to homework, projects, and tests.

Disability Statement:
If you are a student with a documented disability who will require accommodations in this course, please contact Resources for Disabled Students (RDS; rds.colostate.edu) for assistance in developing a plan to address your academic needs.

Grade Disputes:
In the event that you disagree with a grade assigned, please submit a brief, written explanation accompanied by the original assignment; email is sufficient for the explanation. Within 14 days, the instructors will review your explanation and provide a decision with explanation. If you are still dissatisfied, you may appeal to appropriate academic administrators. Note: this process is not necessary for errors in grading, such as incorrectly recording grades or adding up points.

Figure 31: Syllabus for MECH 580 PHEV Computation Systems Design

Course Development and Delivery

CSU has taken action over the course this grant to put these objectives of this grant into practice and to project the sponsored research in the fields of PHEVs, energy systems and lifecycle analysis into the classroom. In support of this program and the base teaching load in the Department of Mechanical Engineering at CSU, CSU has developed three courses (*Vehicle Electrification*, *Design of Energy Storage for Vehicles* and *Advanced Mechanical Systems*) and two more with colleagues at the Georgia Tech (*Hybrid Electric Vehicle Powertrains* and *Renewable Energy Systems*). These courses are all designed to be part of CSU's modern, systems–literate and industrially–relevant Mechanical Engineering curriculum. In a model of systems engineering methods, the subjects and learning objectives for these courses were developed through a formal, interview–based needs assessment for the US Automotive Industry. As a result, these courses are fully informed by the requirements of industry and include such concepts as model–based simulation and design (in MATLAB/Simulink), project–based learning, industry–inspired open–ended design problems and more. The results of this work have now been published in the engineering education literature and the courses support a *Sustainable Transportation* certificate program in the College of Engineering.

As part of this program, CSU has developed and instruct a professional development workshop series on the subject of hybrid and electric vehicles. This workshop is held at the College of Natural Sciences Education and Outreach Center, at CSU in Fort Collins. This workshop includes seminar presentations, hands–on activities designed for the classroom, a field trip to CSU's Engines and Energy Conversion Laboratory and the opportunity to physically explore PHEVs. Activities focused on Regenerate! kits that explore the science of rechargeable batteries and regenerative braking in advanced electric vehicles. The outcomes from these educational efforts have been outstanding. Undergraduate students from CSU are now competitive for outstanding industrial positions at internationally–recruiting companies and many have taken positions at General Motors, Tesla Motors, Boeing and General Electric. Recent graduates include nine MS and PhD students into the automotive research and energy industry and two postdoctoral scholars into assistant professor positions in academia (at West Virginia University–Institute of Technology and Utah State University).

Course Assessment and Redesign

As an example of the course assessment and redesign activities of this grant, described are some recent efforts wherein Dr. Bradley and a co–instructor have made significant improvements to ENGR 580–A1 *Hybrid Electric Vehicle Powertrains* using a systematic summative assessment technique to identify potential improvements. To perform this assessment, assessment data was collected throughout the semester and then synthesized. The data collected included entrance and exit surveys; evaluation rubrics for homework, exams and the project report and presentation; student evaluations of teaching and the course; and anecdotal / miscellaneous notes. Entrance surveys asked students to rate their confidence and interest in about 50 topics, which it is felt are central to being a "Hybrid Electric Vehicle Engineer", before they began the course. After the completion of the course, exit surveys asked students to rate the gains they believed they made on each topic, as a result of taking the course. Homework and exam rubrics were created to extract evaluations of the learning and knowledge of students from these assignments. Similarly, project report and presentation rubrics were designed to pull out information about the attainment of learning objectives, through the lens of the project. Teaching evaluations were reviewed together with input from the exit surveys about students' evaluations of the course. Finally, anecdotal and miscellaneous notes, comments, observations, etc. were included to supplement where applicable. The outcome of this process was a summative assessment of the state of each learning objective in terms of instructors' emphasis and student performance. After all the data were collected and analyzed, an assessment meeting was held between the two co–instructors of the course (who are also the co–authors of this paper) to go through all the results and determine the issues and successes, as is required in the first step of the redesign process. The summary of what was found and implemented is as follows (for reference, the learning objectives are presented in the adjoining text box):

1. Of the six learning objectives, four were well satisfied, one requires major changes and one requires deeper assessment.
    a. Objective 5, regarding the construction of simulation models, needs major improvements as students were underprepared for heavy use of Simulink and not enough time was dedicated to application of the models created.
    b. Objective 4, regarding evaluation of design tradeoffs, require better assessment since only the project measured it, but was a team project. It seemed that some students did poorly with it while others did well, so a more direct and individualized assessment will be used in Spring, 2012. At the root of the issue may be students' struggles with ambiguity inherent in real–world design.
2. Exams and homework need revision for timing, difficulty and grading clarity.
3. Project teams were weak in their demonstration of argumentation skills as well as oral and written communications.
4. In future offerings, no teams will be all undergraduate in constitution. As well, individual

contributions to teams will be evaluated with tools like CATME (http://www.catme.org).

5. Students enjoyed discussion about the behind–the–scenes of the PHEV industry.
6. Students suggested that a full PHEV example should be given from the start of the course and then referred back to throughout as a reference for comparison to new information. Since there is now a vehicle lift in place and many PHEV cars on site, it was felt that these should be utilized.
7. Students struggled with electromagnetics and motors due to most of them being ME in discipline. The EE portion of the course ported from Georgia Tech had to be redesigned on–the–fly; it was later noted that there is a mix of EE and ME students in their course at Georgia Tech.
8. The textbook wasn't helpful to many students and is being reconsidered.
9. More formative assessment will be used to monitor students' learning on new topics. As well, more assessment of course topics (e.g. thermodynamics, motors, communication skills, etc.) will be done as the course progresses and assessment of "PHEV–relevant policies and regulation" added.
10. The project was too crammed into the end of the semester and will instead be spread throughout.
11. Less lecture and more active learning pedagogy will be used to accommodate different learning styles and enhance learning opportunities and motivation in the classroom.
12. Students said the challenge of the course was high and there is agreement that high standards and challenging problems will continue to be the hallmark of this course to promote excellence and deep learning.

The results of this assessment and means for course improvement have been submitted to the Special Issue on Assessment in the European Journal of Engineering Education, 2012. The needs assessment, “Designing a Hybrid–Electric Vehicle Program: Results from an industry–informed needs assessment,” was utilized to structure course objectives and to define outcomes for students and their potential employers. CSU conducted 17 industry interviews, 9 of which were used to supplement course content. Core course content was aligned with and supported by Subject Matter Experts review. See "From course assessment to redesign: a hybrid–vehicle course as a case illustration" (**Publications, Papers and Conference Proceedings**; Stanton and Bradley, 2013).

3.3.4 Georgia Tech Developed Courses

ECE 8803: Dynamics and Control of Hybrid Electric Vehicles Syllabus
Instructor: Professor David Taylor, david.taylor@gatech.edu
References (freely available online through the library):
1. *Propulsion Systems for Hybrid Vehicles* (2E), Miller, IET, 2010.
2. *Modern Electric, Hybrid Electric and Fuel Cell Vehicles* (2E), Ehsani/Gao/Emadi, CRC 2009.
3. *Vehicle Propulsion Systems* (2E), Guzzella/Sciarretta, Springer, 2007.
4. *Automotive Control Systems* (2E), Kiencke/Nielsen, Springer, 2005.

Prerequisites: Graduate standing
Technical Interest Area: Systems and Control
Objective: To provide a comprehensive understanding of hybrid electric vehicles, by considering three distinct levels of powertrain control – power management logic to generate desired operating points, system–level feedback to stabilize desired operating points and component–level torque control.

Table 5 **ECE** 8803: Dynamics and Control of Hybrid Electric Vehicles Topics	
Topics: Introduction to Hybrid Electric Vehicles	3 hours
Motivation, Components and Architectures (Series, Parallel, Power Split)	
Prerequisite Theory in Systems and Control	9 hours
State Equations Derived from Conservation Principles	
Relationship Between Transient and Steady–State Modeling Numerical Methods for Approximating Solutions of State Equations	
Equilibrium States, Stability Theory, Feedback Control, Gain Selection	
Fundamentals of Modeling, Control and Simulation of HEV Powertrains	24 hours
Vehicle Dynamics: Acceleration and Braking	
Transmission Dynamics: Gears and Clutches	
Energy Storage Dynamics: Batteries and Capacitors	
Efficiency Maps of Combustion Engines and Electric Machines	
General State–Space Form of Electromechanical Powertrain Dynamics	
Feedback Controllers to Stabilize Commanded Operating Conditions	
Power Management Logic to Determine Controller Reference Commands	
Case Studies: Toyota Prius and GM Multi–Mode Architectures	
Component Sizing Based on Performance Goals Optimization–Based Assessment of Achievable Performance	
Detailed Consideration of Combustion Engines and Electric Machines	9 hours
Efficiency Maps as Result of Component Physics and Torque Control	
Combustion Engines: Spark/Compression Ignition, Operating Cycles	
Electric Machines: Induction/Synchronous, Switched Mode Converters	

ME 4823: Hybrid–Electric Vehicle Powertrains Syllabus

Instructor: Dr. Michael Leamy (ME), 132 Erskine Love Building, michael.leamy@me.gatech.edu
Optional (available online through GEORGIA TECH library): M. Ehsani, Y. Gao, S.E. Gay and A. Emadi, *Modern Electric, Hybrid Electric and Fuel Cell Vehicles*, CRC Press, 2005
Prerequisites: ECE–3710

Table 6 ECE 4823: Hybrid Electric Vehicle Powertrains Topics	
Introduction to Hybrid Electric Vehicles	1.5 hours
Course Description, Components and Architectures	
Power–Split EVT Architectures	7.5 hours
Planetary Gearing	
One–Mode EVT	
Two–Mode EVT	
Vehicle Longitudinal Dynamics	4.5 hours
Newton’s Law	
Mass Factor	
Loads	
Traction	
Gearing	
Hybrid Braking 1.5 hours	1.5 hours
Exam	1.5 hours
High–Level Series/Parallel Hybrid Design	6.0 hours
Performance Goals	
Sizing of Components	
Supervisory Control	
Simulation Tools	
Team Project Review Meetings (in class)	1.5 hours
Electric Machines and Drives	7.5 hours

Table 6 ECE 4823: Hybrid Electric Vehicle Powertrains Topics	
Electromechanical Energy Conversion Fundamentals	
PM Synchronous Machines, Structure and Operation	
Switched–Mode Converters for Control	
Torque–Speed Capabilities, Efficiency Optimization	
Internal Combustion Engines	7.5 hours
Classification, Terminology, Components	
Operating Characteristics, PV Diagrams	
Engine Cycles: Otto, Diesel, Dual, Miller	
Efficiency Comparisons	
Exam 2 (in class)	1.5 hours
Energy Storage	3.0 hours
Batteries	
Supercapacitors	
Conclusion	1.5 hours
Recap and Future Trends	
Group Project Presentations(during final exam period)	2.5 hours

ME8813 – Simulation–Based Design of Hybrid–Electric Vehicles Syllabus
Instructor: Dr. Michael Leamy (ME), 132 Erskine Love Building, michael.leamy@me.gatech.edu
Spring 2012, 12:05 – 1:25, Tuesday and Thursday, Instruction Center 219

Table 7: ME8813 – Simulation-Based Design of Hybrid-Electric Vehicles Topics	
Introduction to HEVs	1.5 hours
Course Description, Components and Architectures	
Introduction to Simulink/Simscape for HEV design	1.5 hours
HEV Mechanics and Modeling	4.5 hours
Vehicle Longitudinal Dynamics	
Hybrid Braking	
Internal Combustion Engines Modeling	
Transmission Modeling	
Electric Machine Modeling	
Energy Storage Modeling	
Controls Modeling	
Backward– looking Simulation of HEVs	9.0 hours
Series/Parallel/Powersplit Modeling	
Performance Goals	
Sizing of Components	
Supervisory Control	
Dynamic Programming	
Forward–looking Simulation of HEVs	6.0 hours
Series/Parallel/Powersplit Modeling	
Supervisory Control	
Midterm Exam	1.5 hours
Case Study 1: Toyota THS–II Powersplit	3.0 hours
Case Study 2: GM 2–Mode Powersplit	3.0 hours
Simulation Lab	12.0 hours
Group HEV design	
Group Project Presentations 3.0 hours	

Learning Objectives:

After completing this course, the student will be able to:

1. Identify and describe qualitatively HEV powertrain configurations (series, parallel and power–split).
2. Identify and describe the basic tenets of simulation–based (or model–based) design and its role in the design process.
3. Describe basic operating principles of HEV powertrain components to include internal combustion engines, electric machines, gear trains and other torque couplers.
4. Create advanced backward– and forward–looking simulations of HEVs using industry–standard simulation tools such as Matlab/Simulink/SimScape.
5. Use simulation tools to calculate vehicle performance metrics for example HEV powertrains.
6. Use simulation–tools to test and develop supervisory and low–level control of HEV powertrains and their components.
7. Evaluate design tradeoffs for basic HEV powertrain concepts using simulation tools.
8. Perform optimization studies using simulation to assist in HEV component design and selection.

Advanced Electric Drive Vehicles: A Professional Short Course
Instructor: Professor Jerome Meisel, Georgia Tech, email: jmeisel@ee.gatech.edu
Introduction: The light–duty vehicles included in this course are defined as vehicles having a gross weight not greater than 6,000 lbs (2727 kg). The U.S. light–duty fleet consists of approximately 236 million vehicles categorized as (i) passenger cars including sizes ranging from small compact vehicles to large sedans and (ii) trucks that include sport–utility vehicles (SUVs) built on a truck frame and pickup trucks. Conventionally these vehicles have powertrains powered by an internal–combustion (IC) engine that can be spark–ignited (SI) or combustion ignited (CI – Diesel). These IC engines most often use a petroleum based fuel refined from oil. At present, the U.S. uses approximately 17.1 million barrels of oil per day with approximately 2/3 of this oil being used to supply the fuel needs for the light–duty fleet IC engines[1]. Domestic oil production is approximately 5.1 million barrels per day, thus requiring 12 million barrels per day of imported oil.[2] In order to reduce the need for these vast daily quantities of oil, recent efforts have been made to use some alternate fuel such as ethanol to replace some of the fuel derived from oil. The purpose of this short course is to present a complementary technological approach involving a modified powertrain that uses electric energy in one of three ways as a means to reduce consumed energy derived from oil. These three approaches are briefly as follows:

1. To simply replace the IC engine with a pure electric powertrain, thus producing a battery–electric vehicle (BEV). The consumed electric energy is then replaced by energy from the electric power grid, thus, in effect, powering these vehicles from all of the means for generating electric energy including coal, nuclear, hydro and renewables such as wind and solar.
2. To include an electric drive with an IC engine such that the synergistic control of these two drive trains reduces the consumption of the oil–based fuel, thus producing a charge–sustaining hybrid–electric vehicle (HEV). These HEVs are not connected to the grid for recharging with only the oil–based fuel being consumed with the vehicle achieving more miles–per–gallon than a conventional IC engine–only vehicle due to this powertrain hybridization.
3. To modify an HEV powertrain such that net electric energy is consumed thus substituting electric energy for oil–based energy. The consumed electric energy is replaced by energy from the electric power grid, thus producing a PHEV.

In summary, this short course presents the details of the components required for BEVs, HEVs and PHEVs. Also presented are the architectural structures in which these components are generally arranged to form the respective vehicle powertrains. A key system aspect of these powertrains that now include

electric energy components involves the required coordinated control algorithms that, in the case of HEVs and PHEVs, need to synergistically blend two sources of driving torque. Finally, this short course also considers the impact PHEV powertrains would have on the electric power systems, as well as the net two emission products; namely the greenhouse gas CO_2 and the EPA regulated emission gas NO_x.
This self–learning professional short course is organized into twelve lessons that are essentially self–contained. Thus these individual lessons can be studied in any order. They are each organized to have two files; namely a PowerPoint file and a Word file. The Word files contain a summary of the material to be learned in the lesson, followed by a detailed explanation of the individual slides in the PowerPoint file. As a self–learning course, the Word file should be studied in parallel with the PowerPoint slides. The content of the lessons has been designed for about one hour of study by practicing engineer with some automotive background.

[1] Note: 1 barrel equals 42 U.S. gallons.
[2] Introduction [1]: J. Mouawad, "The Spill vs. a Need to Drill", N.Y. Times, Week in Review, May 2, 2010, pgs. 1, 3.

Table 8: Table of Lessons
Lesson–1: On–Board Energy Storage for Battery–Electric and Hydrogen–Fuel Cell Vehicles.
Lesson–2: The Series and Parallel Hybrid–Electric Vehicle Powertrain Architectures.
Lesson–3: Single – Planetary Split – Power Architectures.
Lesson–4: An Analytic Foundation for the Two–Mode Hybrid–Electric Powertrain with a Comparison to the Single–Mode Toyota Prius THS–II: Part 1: Four Fixed–Gear Operation.
Lesson–5: An Analytic Foundation for the Two–Mode Hybrid–Electric Powertrain with a Comparison to the Single–Mode Toyota Prius THS–II Part 2: Two Split–Power Modes.
Lesson–6: Hybrid–Electric Powertrain Components: Electric Motors /Generators Part 1: Conventional Dc– and Brushless Dc–Machines.
Lesson–7: Hybrid–Electric Powertrain Components: Electric Motors /Generators Part 2: Induction Machines.
Lesson–8: Hybrid–Electric Powertrain Components: Part 3: Power Electronic Converter Circuits.
Lesson–9: Introduction to Plug–In Hybrid–Electric Vehicle (PHEV) Design Concepts.
Lesson–10: Topic–1: Projected MPG increases and Required Grid–Supplied Electric Energy for PHEVs.
Topic–2: Vehicle–to–Grid (V2G) Operation.
Lesson–11: PHEV Effect on Electric Utility Operation.
Lesson–12: PHEV Tail Pipe and Power Plant Emissions.

4.0 Products Developed

4.1 Publications, Papers and Conference Proceedings

CSU

1. T. Campbell, T.H. Bradley "A model of the effects of automatic generation control signal characteristics on energy storage system reliability " Journal of Power Sources, Volume 247, 1 February 2014, Pages 594–604
2. K. Stanton, T.H. Bradley "From course assessment to redesign: a hybrid–vehicle course as a case illustration," European Journal of Engineering Education, DOI: 10.1080/03043797.2013.826181
3. Al–Alawi, B., and Bradley, T.H., "Review of Hybrid, Plug–in Hybrid, and Electric Vehicle Market Modeling Studies," Renewable and Sustainable Energy Reviews, Volume 21, May 2013, Pages 190–203
4. Geller, B., and Bradley, T.H. "Quantifying Uncertainty in Vehicle Simulation Studies," SAE Int. J. Passeng. Cars – Mech. Syst. 5(1):2012, doi:10.4271/2012–01–0506

5. Davis, B. M., Bradley, T. H. "The Efficacy of Electric Vehicle Time–of–Use Rates in Guiding Plug–in Hybrid Electric Vehicle Charging Behavior," IEEE Transactions on Smart Grid, DOI: 10.1109/TSG.2012.2205951
6. Wood, E., and Bradley, T.H., "Investigation of Battery End–of–Life Conditions for Plug–in Hybrid Electric Vehicles," Journal of Power Sources 196 (2011) 5147–5154
7. Salisbury, S., Geller, B., Fox, M., and Bradley, T.H., "Detailed Design of a Fuel Cell Plug–in Hybrid Electric Vehicle," SAE World Congress, Detroit, MI, 2013–01–0560
8. Fox, M., and Bradley, T.H. "Decision Support for Vehicle Technology Selection and Optimal Component Sizing: Colorado State University EcoCAR 2 Vehicle Design," ASME/SAE/AIAA 10th International Energy Conversion Engineering Conference, July–August 2012, Atlanta, GA.
9. Kambly, K., and Bradley, T.H., "Geographical and Temporal Variations in Plug–in Electric Vehicle HVAC Loads" ASME/SAE/AIAA 10th International Energy Conversion Engineering Conference, July–August 2012, Atlanta, GA.
10. Geller, B., Fox, M., Alvarado, C., Barrett, P., Habib, H., Koelling, Z., Malakoutirad, M., Miksch, J., Salisbury, S., Sewell, S., Shea, C., Zevenbergen, M., Quinn, J., and Bradley, T., "Design of a Fuel Cell Plug–in Hybrid Electric Vehicle in a Range Extending Configuration by Colorado State University for the EcoCAR 2 Competition," SAE 2012 International Powertrains, Fuels Lubricants Meeting, September 18–20, 2012, Malmo, Sweden.
11. Geller, B., Fox, M., Bradley, T.H., Kalhammer, F., Kopf, B., and Panik, F., "Plug–in Fuel Cell Vehicle Technology and Value Analysis," EVS26, May 6–9 2012, Los Angeles, California
12. Lutz, M., Zimmerle, D., Huff, B., and Bradley, T.H. "Design and Construction of a Grid–attached Storage Simulator," ASME International Conference on Energy Sustainability, Aug. 7–10 Washington, D.C., ESFuelCell2011–54541, 2011.

Theses – CSU (Present positions)

1. Matthew Fox, MS 2012 (Tesla Motors), Assessment, design and control strategy development of a fuel cell hybrid electric vehicle for CSU's EcoCAR
2. Jacob Renquist, MS 2012 (General Motors), *Economic and Environmental Analysis of Fuel Cell Powered Materials Handling Equipment*
3. Brian Johnston, MS 2012 (Lightning Hybrids), Vehicle to Grid (V2G) in the Context of the Department of Defense Environmental Initiatives
4. Barbara Davis, MS 2010 (Electric Power Research Institute), *Understanding the Effects and Infrastructure Needs of Plug–in Electric Vehicle (PEV) Charging*
5. Casey Quinn, MS 2011 (NSG Engineering Solutions) *State of Charge Resolved Modeling of Vehicle to Grid Systems*
6. Eric Wood, MS 2011 (National Renewable Energy Laboratory), *Investigation of Battery End- of-Life Conditions for Plug- in Hybrid Electric Vehicles*

7. Markus Lutz, MS 2012 (BMW Munich), *Development of an Electric-drive Powertrain Test Stand and Battery-to-Grid Storage Test Stand*
8. Baha Al–Alawi, PhD 2012 (CSU), Decision support tools for policy development to support market penetration of plug–in vehicles
9. Timothy Campbell, MS 2012 (Woodward Governor), Dynamic Modeling and Control of Battery–to–Grid Energy Storage Systems

Georgia Institute of Technology

Ken Cunefare, David Taylor, Jerome Meisel, Michael Leamy

1. Arata, J.P., Leamy, M.J., Meisel, J., Cunefare, K., Taylor, D.G., 2011, "Backward–looking simulation of the Toyota Prius and General Motors Two–Mode power–split PHEV powertrains," *SAE International Journal of Engines*, **120** (1): pp. 1281–1297.
2. Meisel, J. "Kinematic Study of the GM Front–Wheel Drive Two–Mode Transmission and the Toyota Hybrid System THS–II Transmission," 2011 SAE World Congress, Paper No. 2011–01–0876, April, 2011.
3. Arata, J.P., Leamy, M.J., Cunefare, K., 2012, "Power–Split PHEV Control Strategy Development with Refined Engine Transients," *SAE International Journal of Alternative Powertrains*, **1** (1): 119–133.
4. Taylor, D.G. and Katariya, A., 2012, "Dynamic modeling and feedback control of a two–mode electrically variable transmission," *Proceedings of the 2012 IEEE International Electric Vehicle Conference*, Greenville, South Carolina, 7 pages, March.
5. Bole, B., Coogan, S., Cubero–Ponce, C., Edwards, D., Melsert, R., Taylor, D.G., 2012, "Energy management control of a hybrid electric vehicle with two–mode electrically variable transmission," *Proceedings of the International Electric Vehicle Symposium, Los Angeles, California*, 13 pages, May.
6. Pei, D., Leamy, M.J., 2013, "Dynamic Programming–Informed Equivalent Cost Minimization Control Strategies for Hybrid–Electric Vehicles," *Journal of Dynamic Systems, Measurement and Control*, accepted for publication.
7. Pei, D., Leamy, M.J., 2013, "Forward–Looking Simulation of the GM Front–Wheel Drive Two–Mode Power–Split PHEV Using a Dynamic Programming–Informed Equivalent Cost Minimization Strategy," *SAE International Journal of Alternative Powertrains*, **2** (2): 379–390.
8. Samba Murthy, A. and Taylor. D.G., 2013, "Regenerative braking of battery–powered converter controlled PM synchronous machines," *Proceedings of the IEEE Transportation Electrification Conference and Expo*, Detroit, Michigan, 6 pages, June.
9. Taylor, D.G., 2013, "Systematic approach to the modeling and control of hybrid electric vehicle powertrains," *Proceedings of the IEEE Transportation Electrification Conference and Expo, Detroit*, Michigan, 6 pages, June.
10. Meisel, J., Shabbir, W., Evangelou, S., 2013, "A Practical Control Methodology for Parallel Plug–In Hybrid Electric Powertrains," accepted for publication: *The 9th IEEE Vehicle Power and Propulsion Conference (VPPC 2013)***,** October 15–18, 2013, Beijing, China.
11. Meisel, J., Shabbir, W., Evangelou, S., 2013, "Evaluation of the Through–The–Road Architecture for Plug–In Hybrid Electric Vehicle Powertrains", 2013, Submitted for publication: *IEEE Vehicle Electronics Conference (IEEE–VEC 2013)*, Santa Clara, California, October 23–25, 2013.
12. Meisel, J., Shabbir, W., Evangelou, S., 2013, in final preparation: "Implementable Uniform Control of PHEV and PHEV Powertrains with Emphasis on the Through–The–Road Parallel Architecture", to be submitted July, 2013 to: *IEEE Transactions on Vehicular Technology.*

Theses: Georgia Institute of Technology

1. J. Arata, "Simulation and Control Strategy Development of Power–Split Hybrid–Electric Vehicles," MS Thesis, Georgia Tech, ME, March 2012.
2. M. Omernick, "Development of a Modular Platform for Embedded Control Systems Laboratory Coursework," MS Thesis, Georgia Tech, ECE, May 2012.
3. A. Katariya, "Dynamic Modeling and Feedback Control with Mode–Shifting of a Two–Mode Electrically Variable Transmission," MS Thesis, Georgia Tech, ECE, August 2012.
4. D. Pei, "Development of Simulation Tools, Control Strategies, and a Hybrid Vehicle Prototype," MS Thesis, Georgia Tech, ME, November 2012.
5. A. Samba Murthy, "Analysis of Regenerative Braking in Electric Machines," MS Thesis, Georgia Tech, ECE, May 2013.

4.2 Website or other internet sites that reflect the results of the project

VEEP is a multi–linked approach combining PHEV education at the secondary, professional, and postgraduate levels. The goal is to educate the next generation of automotive technicians, engineers, and first responders on electric vehicle design, function, and safety.

- Collection of Educational resources on Gooru: "Hybrid Electric Vehicles and Beyond"
- http://www.goorulearning.org/#collection-play&id=be7a5a89-e4fd-44a6-8c39-2b317246dfb5
- General VEEP website: http://www.engr.colostate.edu/VEEP/
- Hybrid Electric Vehicle Education (University Level Education) http://www.engr.colostate.edu/me/PHEVe/
- EcoCAR 2 CSU http://www.engr.colostate.edu/me/pages/undergraduate/senior-projects/ecoCar-2/EcoCar2-1.html
- Facebook pages:
  - Native Talent and Technology https://www.facebook.com/pages/Native-Talent-and-Technology/276285045805820
  - Vets Get Technical https://www.facebook.com/VetsGetTechnical
  - Women Get Technical https://www.facebook.com/WomenGetTechnical

- Mobile app for ACC Veterans (site for online access until iTunes approval, which is pending):
- On a computer, visit www.previewyourapp.com and use **accapp** in both the email and password fields. The app can be explored here as if it's on a smartphone.
  - If reviewing on an iPhone, the Preview App can be downloaded at:
    - http://itunes.apple.com/us/app/preview-your-app/id474947166?mt=8
  - Install and launch the app then use **accapp** in both the email and password fields to load the app. This is by far the best way to preview the app.

4.3 Networks or collaborations fostered

This grant allowed CSU to foster collaboration with many OEMs and industrial partners including:

- (2012–2013)
  - "Transportation Sector Modeling," Electric Power Research Institute
  - "Small Engine Propulsion System Demonstrator" Air Force Research Laboratory
- (2011–2012)
  - "Small Hybrid Propulsion System Demonstrator, Follow–up" Air Force Research Laboratory
- (2011–2014)
  - "EcoCAR 2" US Department of Energy and General Motors LLC
- (2011–2012)
  - "Real World Energy Use Modeling and Experiments for Conventional and Electrified Transportation," Electric Power Research Institute
- (2010–2011)
  - "Financial Models for Utility Market Transformation," US Department of Energy National Renewable Energy Laboratory – Joint Institute for Strategic Energy Analysis
  - "Bridge Study for Comparison of Costs and Benefits of Battery–to–Grid and Vehicle–to–Grid Systems," University of California at Davis / California Energy Commission
  - "Plug–In Hybrid Electric Vehicle Modeling and Decision Support – Follow–up," Electric Power Research Institute
  - "Small Hybrid Propulsion System Demonstrator," Air Force Research Laboratory
- (2010)
  - "Economic and Environmental Analysis of Fuel Cell Powered Materials Handling Equipment," and "Plug–In Hybrid Fuel Cell Vehicle Evaluation Phase 0," Electric Power Research Institute
  - "Dwight David Eisenhower Transportation Fellowship Program – Eric Wood," US Department of Transportation

Arapahoe Community College collaborations:

- Developed and extended ACC's collaboration with CSUME and RRCC to implement a firefighter training program and other programs across the State.
- Created a relationship with the ongoing STEM teacher training programs at CSU.
- Developed relationships with the Project FEVER (Denver Metro Clean Cities Coalition) and Veterans Green Jobs as part of the Contract's goal of seeking both public and private partners for the overall effort.
- ACC retained Jonathan Greenwald, ACC's EMT Department Director, and John Hallsten, Director of ACC's Law Enforcement Academy, to modify aspects of the NFPA curriculum modules for EMT and law enforcement first responders.
- ACC developed extensive marketing plans in collaboration with law enforcement departments throughout Colorado, the MHRETAC – EMT professional organization, the Emergency Medical Services Association of Colorado, and the Colorado Clean Air Coalition.
- ACC collaborated with ProjectWISE of Denver in conducting a women's car care clinic.

- ACC collaborated with the DIC in introducing the Native American population to career opportunities in the automotive technology field.

Douglas County School District collaborations:

- DCSD established working relationships with over 80 local automotive, technical, and sustainable energy businesses through Career Connect programs established under the grant.

CSU Collaborations:

- Women Veterans of Colorado
- CSBR/National Defense Industry Association
- Buckley Air Force Base
- Bo Matthews Center of Excellence/Community Referral and Resource
- Denver Metro Small Business Development Center
- US Chamber of Commerce Boots to Suits
- Fort Carson Army Post
- The Space Foundation
- Veterans Green Jobs

Other CSU collaborations established across industry, educational and professional organizations:

- National Fire Protection Association (NFPA)
- National Highway Administration (NHA)
- A variety of Original Equipment Manufacturers (OEM)
- Denver Metro and Northern Colorado Clean Cities
- College of Natural Sciences Education and Outreach Center (CSU)
- Center for Multiscale Modeling of Atmospheric Processes (CSU)
- EcoCAR 2 Vehicle Innovation Team, Dept. of Mechanical Engineering (CSU)
- Gooru
- Northern Colorado Clean Cities
- Denver Metro Clean Cities (Project FEVER: Fostering Electric Vehicle Expansion in the Rockies)
- Drive Electric Northern Colorado (Electrification Coalition)
- Douglas County Education Foundation and Douglas County School District
- Poudre School District
- Center for Multiscale Modeling of Atmospheric Processes (CSU)
- Society of Women Engineers Rocky Mountain Section
- Northern Colorado Business Report

4.4 Undergraduate Courses

For the future workforce, the undergraduate degree granting programs in the Mechanical Engineering Department developed courses for a new electric vehicle concentration (a certificate program). Courses included systems engineering in these vehicle types, relationships to support systems, and sustainability from both an environmental and business perspective.

These efforts leveraged the distance education programs at the universities to enlarge scope, impact and program sustainability. The following undergraduate courses were developed and implemented under the grant:

	# students	# semesters offered to date
Hybrid Electric Vehicle Powertrain Engineering (Georgia Tech: *ME 4823, ECE 4803*; CSU: *ENGR 580A1*)	238	4 (each university)

Frequency: Every Fall semester
Description: PHEV Powertrain is a cross–listed senior elective special topics course developed jointly by Georgia Tech's K. Cunefare, M. Leamy, and D. Taylor, and considers essential powertrain features, including vehicle dynamics, internal combustion engines, electric propulsion systems, energy storage, regenerative braking, and design, performance and control. This course ported to CSU in the spring of 2010. At CSU, this course introduces students to the engineering design and analysis of hybrid–electric vehicle (PHEV) powertrains. Increasingly stringent limits on emissions, as well as attention to conservation of hydrocarbon fuels is driving the development of alternative power sources for vehicles, with hybrid–electric powered vehicles rapidly developing as a viable solution. The course is interdisciplinary between ME and ECE – a natural consequence of the technological integration of electrical and mechanical systems inherent in hybrid powertrains.

	# students	# semesters offered to date
Vehicle Energy Storage Systems (CSU: *MECH 598A/MECH 523)*	15	1

Frequency: Every Spring semester
Description: This course consists of three 5–week modules. Each module introduces and analyzes one technology for electrochemical energy storage. A detailed introduction to the technology from an electrochemical, thermal, and materials perspective is provided for the first half of each module, and a. systems–level introduction to relevant applications, sustainability impacts, powerplant design, and application level optimization is provided for the second half.

4.5 Graduate Courses

The following graduate courses were developed and implemented under the grant:

	# students	# semesters offered to date
Transportation Electrification (CSU: *MECH 680 A4*)	14	2

Frequency: Biennially during odd Fall semesters
Description: This course seeks to understand the energy connection between the electrical grid as well as personal and public transportation needs, including knowledge of the technical, economic, policy, and consumer behavioral aspects of the grid and of personal transportation. Tools and techniques for interfacing vehicles to the electrical grid are presented, for quantifying their costs and benefits to the electrical system operators, and for analyzing the commercialization of transportation electrification technologies.

	# students	# semesters offered to date
EV/PHEV Computational System Design (CSU: *MECH 580*)	8	1

Frequency: Every Fall semester
Description: This course uses the modeling and design languages of Modelica and ModelCenter to

perform system level studies of vehicle energy consumption, vehicle use behavior, stochastic economic costs, benefits analyses, and more. This course presents the tools of modeling and optimization of PHEV energy systems, drivelines, and architectures with the goals of developing the skills and techniques that will inform the next generation of innovation for PHEVs.

Simulation–Based Design of Hybrid–Electric Vehicles # students # semesters offered to date
(Georgia Tech: *ME 8813*) 10 1
Description: The objective of this special topics course is to introduce the fundamentals of modeling and simulation in design of hybrid–electric vehicles, with a focus on developing energy management and control strategies. Course content focuses on simulation techniques and their application to the design of hybrid–electric vehicle powertrains, to include sizing and optimizing components, developing supervisory control strategies, and establishing performance metrics.

Dynamics and Control of Hybrid–Electric Vehicles # students # semesters offered to date
(Georgia Tech: *ECE 8803*) (49 campus+20 distance learning) 69 2
Frequency: Every Fall semester
Description: The objective of this course is to provide a comprehensive understanding of hybrid electric vehicles by considering three distinct levels of powertrain control – power management logic to generate desired operating points, system–level feedback to stabilize desired operating points, and component–level torque control.

Table 9: University Level Education – Curriculum Development at CSU and Georgia Tech

Level and Classes Taught	**Total Number of Students**	**Number of Semesters**
Undergraduate		
Hybrid Electric Vehicle Powertrain Engineering	238	4
Vehicle Energy Storage Systems	15	1
Graduate		
Transportation Electrification	14	2
EV/PHEV Computational System Design	8	1
Simulation–Based Design of Hybrid–Electric Vehicles	10	1
Dynamics and Control of Hybrid–Electric Vehicles	69	2
Professional Short Courses		
Maintenance Practices and Design of PHEVs for Engineers (CSU)	Ongoing online course, in process	
Self–Study Short Course: Advanced Electric Drive Vehicles (GT)	Ongoing, online course in process	
Total Number of University Students During Grant Period	**354**	

4.6 Short Courses

The following professional short courses were developed and implemented under the grant:
Engineering Maintenance Process:
Maintenance Practices and Design of PHEVs for Engineers (CSU)
Frequency: Online/distance learning (Online Plus)
Description: MECH 503 Course explores the design for, and development and management of effective maintenance programs applicable to typical industrial environments. Topics include: need and benefit derived from effective maintenance programs, maintenance organization structure based on business modeling and economic analysis of investment alternatives, technologies applicable to maintenance program execution, fundamental statistical tools employed to determine maintenance scheduling and programming, logistics and supply chain concepts critical to maintenance planning and execution, and critical attributes inherent to effective design for maintainability.

Self–Study Short Course: Advanced Electric Drive Vehicles (Georgia Tech)
Frequency: Online/distance learning
Description: This is a self–learning short course that includes details of the components required for BEVs, PHEVs, and PHEVs. Also presented are the architectural structures in which these components are generally arranged to form the respective vehicle powertrains. A key system aspect of many powertrains that now include electric energy components involves the required coordinated control algorithms that, in the case of PHEVs and PHEVs, need to synergistically blend two sources of driving torque. Finally, this short course also considers the impact PHEV powertrains will have on the electric power systems, as well as the net increase or decrease in two emission products; namely the greenhouse gas CO_2, and EPA–regulated emissions of nitrous oxides. This self–learning professional short course is organized into twelve lessons that are essentially self–contained.

4.7 Broader Impact and Sustainability of Program Task

The task's goal was to prepare engineers to work on the mechanical, electrical, and environmental engineering challenges inherent in the HEV field. Particular attention was to be paid to the economic and technical design problems engineers must overcome in order for these advanced technology vehicles to penetrate the automotive market. The overall focus of such a program now dovetails well with existing concentrations within the university, such as CSU's Clean Energy Supercluster, the Energy Institute, the Center for the New Energy Economy, and the Powerhouse Institute.

The university–level educational program will continue to be offered to future students at CSU and Georgia Tech. Graduate students that participated in the program have obtained gainful employment within the industry where they continue to contribute to the field (students have landed at Tesla Motors, Lightning Hybrids, General Motors, Electric Power Research Institute, NSG Engineering Solutions, National Renewable Energy Laboratory, BMW Munich, CSU, and Woodward Governor). Dr Stanton, who was integral to this project, and who was an Engineering Education postdoctoral fellow supported by the program at CSU from 2010–2012, continues to prepare students for college STEM courses by heading the Mathematics Department at Colorado Early Colleges Fort Collins.

4.8 Other Products Developed

Relevant products for K–12 outreach are listed under Key Project Activities. ACC, with the participation of industrial partners including but not limited to the NFPA, the National Highway Administration (NHA), and a variety of Original Equipment Manufacturers (OEM), was responsible for the development of electric vehicle first responder courses within its Emergency Medical Technician (EMT) and Law Enforcement Departments. RRCC concurrently developed a first responders safety course to be offered both on–campus and as workforce development training for professional firefighters. All three first responder courses are products developed under the grant.

ACC was also tasked with developing a three–module short course certificate program for employed automotive professionals focused on the safe repair and servicing of emergent PHEV/EVs. The following short courses were developed and are currently being offered: Hybrid Safety and Theory, HEV to PHEV Conversion, and Diagnosing and Troubleshooting Advanced Technology Vehicles. Many of the instructional modules from these courses have been integrated into the regular academic programs of both Colleges.

No patents were developed under this work.

- NFPA PHEV Safety first responder training modules licensed by ACC and RRCC
    - Modifications of the NFPA PHEV Firefighter training modules by ACC faculty to be in keeping with EMT and Law Enforcement Offices roles at PHEV accident scenes.
- ACC's Advanced Automotive Center's two PHEV Safe Repair and Service modules ACC's Advanced Automotive Center's three PHEV Safe Repair and Service modules
- Licensing agreements between CSUV, ACC, RRCC and NFPA to make use of instructional modules were on August 31, 2013 all modules and materials to be returned to NFPA
- All ARRA and required DOE program reports were generated and submitted on time. Inventories were reviewed throughout the project as scheduled with no discrepancies found.

5.0 Expenditures (Final)

CSUV has expended $4,519,290 of the federally allocated funds. See Table 10. CSUV has provided $1,260,181 cost share which is 21.8% of the contractually committed cost share.

Table 10: Financials		
Total Project Cost	**Federal**	**Non–Federal**
$5,779,491	**$4,519,290**	**$1,260,181**

6.0 Additional Reports Required

6.1.1 Management Reporting (Final Progress Report)

Electronic version uploaded to https://www.eere-pmc.energy.gov/SubmitReports.aspx

6.1.2 Financial Reporting

SF-425 (electronic version) uploaded to https://www.eere-pmc.energy.gov/SubmitReports.aspx

6.1.3 Closeout Reporting (Patent Certification, Property Certification)

Electronic versions uploaded to https://www.eere-pmc.energy.gov/SubmitReports.aspx

6.1.4 Other Reporting (Annual Indirect Cost Proposal, Annual Inventory Report of Federally Owned Property)

Electronic versions of uploaded to https://www.eere-pmc.energy.gov/SubmitReports.aspx