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A SUSTAINABLE APPROACH TO ADVANCED ENERGY AND VEHICULAR TECHNOLOGIES AT THE UNIVERSITY OF KANSAS

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ABSTRACT

In the fall of 2008, the Department of Mechanical Engineering at The University of Kansas began a hybrid vehicle program as an undergraduate senior design project. The purpose of this class is to ensure that the students leaving the curriculum are learning about advanced energy and vehicular technologies to make them attractive candidates for the new wave of energy related jobs. Future efforts of this project will follow the pathway of the Department of Energy's Strategic Approach to Energy Security while keeping objectives realistic and costs manageable.

From the first meetings with the students, a sustainable architecture was set as the approach to the project. The student's definition of sustainability draws from others mentioned in the literature and illustrates the application of engineering techniques to solving real-world problems by holistically approaching the situation from five vectors of success: the environment, energy, economics, education and ethics. Each of these concepts individually addresses specific aspects of sustainability, shaped by the confluence of the ideals of people, planet, and prosperity. Moreover, it is through the multi-leveled application of the vectors of success that the students have developed the means to face the challenges of advanced hybrid automotive technologies.

This paper describes the hurdles faced by the faculty and students upon starting this hybridization program, illuminating methods to minimize the costs involved with beginning a new vehicular program while maximizing the reward to the students and faculty. In particular, the recycling of an iconic vehicular platform, the Volkswagen Super Beetle, has stimulated enthusiasm in the program while also providing a reasonable baseline vehicle. In addition, the reclamation of such a vehicle is inherently economically and environmentally friendly. This has significantly reduced the start-up expenses of the project by taking advantage of a discarded and underutilized resource. Since a hybrid vehicle is a complex electro-mechanical and aerodynamic system, the success of the program ultimately relies upon building relationships with faculty members across many disciplines. As a result, this paper illustrates novel methods of synergy in order to exemplify how multiple disciplines can work independently, yet with a common goal. Furthermore, this work describes the inclusion of energy technologies often not associated with production vehicles, such as solar and wind power. Finally, the authors demonstrate how the five vectors of sustainability fit within the program to ensure continuing success of the curriculum.

INTRODUCTION

The United States automotive industry over the last twenty-four months has undergone a sweeping paradigm shift in philosophy towards fuel economy and away from performance [1-6]. The recent surge in fuel costs, as illustrated in Figure 1, forced everyone to become more aware of the impact of miles per gallon on their finances. While fuel costs have dropped from a peak of over $4.00 per gallon, some believe that a fundamental change in the mindset of manufacturers and customers has occurred [7]. This is evident in a recent General Motors survey that indicates nearly 80% of Americans that plan on buying or leasing a car in the next two years would select a "greener" car over a more aesthetically pleasing alternative [8]. However, for years the auto industry has touted engine power over fuel economy as little consumer or regulatory pressure was placed on their practices as indicated by the decreasing fuel economy values across platforms [9]. As a result, this shortsightedness has led to significant troubles, as sustainable practices were not in place to recover from an inevitable shift in demand [10]. This is particularly disconcerting for the industry

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given the fuel economy standards appearing on the horizon [11].

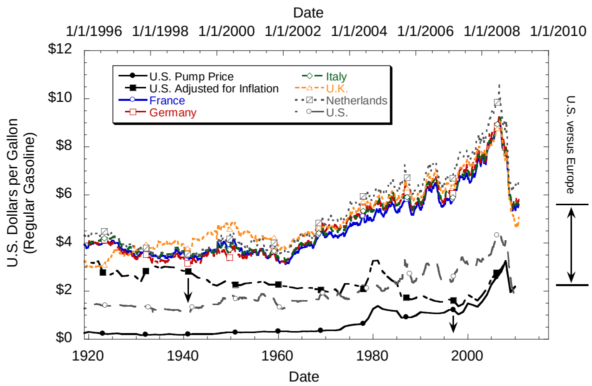

Figure 1. Historical gasoline prices [12-14].

The change in priorities must also occur within a university curriculum, as the traditional view of "gearhead" students going into the automotive field must be replaced with a reflection of the diversity of modern society [15, 16]. Of particular note, current discussions with under-represented students indicate that the perception of automotive engineering needs enhancement with respect to energy, efficiency and the environment. This is where the previous familiarity of the main author working within the automotive sector plays a vital role by being able to relate actual experience of how most vehicular engineering occurs through simulations and modeling activities instead of a garage setting. These models provide a powerful resource that can significantly advance the science of the field [17].

Hence, a comprehensive vehicular design course involving a synergistic theoretical and practical understanding of hybridization, incorporating the next generation of energy capture, storage and power consumption technologies (i.e. alternative fuels, advanced chemistry batteries, and electric vehicle drive) would ensure that graduating students would be leaving with the proper skill set to meet the upcoming demands of the automotive industry. This paper illustrates the lessons learned upon the creation of such a design project geared toward hybrid vehicles.

INITIAL EFFORTS

Shorty after beginning at The University of Kansas (KU), the main author set up meetings with interested students who felt socially and environmentally responsible in their efforts and wanted to make an impact on society. These sessions with the students, who later dubbed themselves the EcoHawks [18], strengthened the conviction that there was a need within the KU Mechanical Engineering Department (ME) course curriculum for a senior design project that would give graduating engineers the tools in great demand by companies that are building eco-friendly, high efficiency vehicles. By the end of the first semester, such a course was developed (ME 645) and added to the curriculum and a mission objective was defined: "By utilizing a multitude of diverse engineering backgrounds, The University of Kansas EcoHawks will design a series hybrid fuel neutral vehicle capable of 500 mpg and construct an operational prototype to test theoretical models under real-world driving conditions".

The original goal of the project was to build a vehicle that would compete in the Shell Eco-Marathon Urban Concept challenge [19] and achieve at least 500 miles per gallon. However, it was soon obvious that this would not happen in the first year. As a new project, the infrastructure and support to build such a vehicle was not readily available. In fact, on the first day of class in late August 2008, the students and faculty member only had a vision and some seed money provided by the KU Transportation Research Institute. There was not any space to build the vehicle on campus and little background knowledge in hybridization or in building passenger cars.

As a result, the students and faculty member decided to take a conservative approach and start with a rolling chassis. By recycling an older vehicle that was not in use, the students already eliminated a large portion of the build and the involved costs. However, one significant issue is that they would be unable to compete in the Eco-Marathon by starting with a "functioning" vehicle. While competing in a challenge is a great way to obtain visibility for the program, it just was not feasible for the students to do so because of the logistics involved. However, since environmentalism is one of the objectives of the program, recycling a vehicle destined for the scrap heap provided a significant energy and material savings. In fact, renovating an older vehicle results in CO_2 reductions of between three to 12 tons over the embedded emissions from building a new vehicle [20]. In addition, by not having specific challenge deadlines, the faculty member could learn and move at a more relaxed pace while remaining cognizant of his own tenure track responsibilities. Additionally, this pace allows students sufficient time for other course work, which is monitored by the faculty member to ensure grades remain consistent.

While there are other challenges, like the EcoCAR Challenge competition [21], where a similar approach is being taken, the faculty member felt that for a first year project with limited resources, it would be better to guide the efforts without deadlines. This would ensure that a conservative tactic could be taken, costs kept moderate and students would have sufficient time to seek out employment as graduation approached. In addition, this allows more flexibility of the faculty member to adapt to student backgrounds along with the freedom to lead the program in the direction he felt appropriate. Finally, the reduced complexity of an older vehicle and the time students spent banging out dents provided a great learning and bonding opportunity for those who never worked on a vehicle. Modern vehicles are complex electro-mechanical devices that nearly require an Automotive Service Excellence (ASE) certification just to change the oil. By choosing an older model with less intricacy, the students were able to proceed faster while encountering fewer obstacles.

Figure 2. 1974 Volkswagen Super Beetle donated to the class.

Therefore, the faculty member made the decision to recycle and upgrade a Volkswagen Beetle in the first year. This iconic design was chosen for a number of reasons:

- Notoriety – everyone is familiar with this vehicle
- Availability – it is the world's number one selling car and was still being built in Mexico up until 2004
- Parts – since it is abundant, spare parts and aftermarket upgrades are readily available
- Enthusiasts – because of its design, many have already transformed it into their own unique visions
- Efficiency – upgrading the vehicle to a hybrid design would result in transforming a dirty (emissions) car into a clean concept vehicle

By chance, a local auto shop (Das Autohaus) had a 1974 Volkswagen Super Beetle that was in reasonable condition for its age (see Figure 2) and was willing to donate it to the program. Das Autohaus also provided temporary workspace to begin the hybrid conversion as space at KU was not immediately available. During this time, the faculty member was able to secure a more permanent hybrid conversion lab in an off campus facility operated by the Aerospace Engineering department.

The first year goal was then set for the EcoHawks to turn this vehicle into a fuel neutral series hybrid. It would be capable of operating on both ethanol (E85) and biodiesel (B100) through the incorporation of modular engine technologies that permits exchange of the installed power generation unit for another that operates using a different fuel; these generator sets support a large battery pack providing power to an electric vehicle drivetrain during vehicle operation. This fuel neutrality, a goal set by the faculty member, leads into one of the many sustainable facets of the project.

From the early classes, the students set sustainability as the motivation of the design project. They even developed their own definition that states sustainability is "the application of engineering principles to solving real-world problems by focusing upon the interconnectedness of the environment, energy, economy, education and ethics". This focus is extremely important, as the engineering curriculum must enable new talent to go forth and lead the innovations of the future [22].

SUSTAINABLE NATURE

The idea of sustainability focuses upon the inherent interconnectedness of people, the planet and prosperity [23, 24]. The principle of engineering sustainability is the application of engineering techniques to solving real-world problems by holistically approaching the situation from five vectors of success: the *environment*, *energy*, *economics*, *education* and *ethics*. These areas naturally overlap and it is through this interrelation that students have the means to face the challenges of advanced automotive technologies at The University of Kansas. The following subsections describe these areas of sustainability, along with how faculty and students incorporate these concepts into current and future directions.

Environmental Sustainability

Environmental Sustainability focuses on the impact of how people fit into the varying ecosystems of the world. Recent movies have piqued public awareness of the possible effects of the excessive use of fossil fuels, while erratic energy costs are drastically changing where consumers choose to spend their money [25, 26]. This has led to an increased demand for hybrid and alternative fuel vehicles which has tempered only recently [27, 28]. In order to be responsive, universities must work to educate students in the impact of their decisions involving these new fuels and vehicles on the environment.

As mentioned previously, by recycling a vehicle the students are removing the significant amount energy and associated greenhouse gas emissions when building a new car from base raw materials. In addition, since the exhaust emissions of an older vehicle are significantly worse than newer models, replacing the antiquated conventional power plant with a newer design will help reduce the environmental impact. Such an idea is the main focus behind the "cash for clunkers" subsidy in Washington [29]. In addition, by adapting the driveline to use eco-friendly fuels, like biodiesel as indicated, the environmental impact of the vehicle is reduced even further [30].

Because of reduced cost and availability, the students are using lead-acid batteries for the first generation battery pack. This results in reduced fuel economy due to the additional weight and reduced energy capacity as compared to newer battery chemistries. However, since lead acid batteries are recyclable and do not contain potential hazards, like cadmium, the slightly increased exhaust emissions compared to more exotic battery options as a result of this decision are considered negligible. Future efforts at designing the vehicle along with driveline components will revisit these decisions and their impact on the ecosystem.

Energy Sustainability

The goal of the students, with respect to building the full-scale vehicle, is to design around fuel neutral series hybrid architecture. This is where the students exchange one power generation unit for an equivalent design that operates on a different fuel. This year, the students are utilizing a diesel generator to run biodiesel fuel produced by the Chemical Engineering Department at KU, while retrofitting a gasoline generator to consume ethanol. The framework of connecting the generator to the system will be common throughout the batteries and electric drive motor; however, this allows future teams to incorporate any type of technology that produces electricity such as turbines or even fuel cells into the platform. By utilizing this modular power design, the vehicle will have the capability to function on power sources that are not even in development right now due to this project's intrinsic flexibility.

The best part of this design principle is that because no singular alternative fuel dominates the energy landscape, the car can utilize whichever fuel is best in a given region. As shown in Figure 3, the Southeastern states have a large propane infrastructure; thus, one could purchase and install a propane generator. This eliminates the intermediary in energy transport, takes advantage of the local energy infrastructure and supports the local economy. No longer is the fuel for a vehicle bound by the price of oil abroad or civil unrest half a world away. By utilizing local availability, the mere use of a fuel neutral vehicle reinforces national security as supported by the Department of Energy's "Strategic Approach to Transportation Energy Security" [31]. Meanwhile, reducing transport distance will increase efficiency by lowering the amount consumed transporting fuel to the consumer.

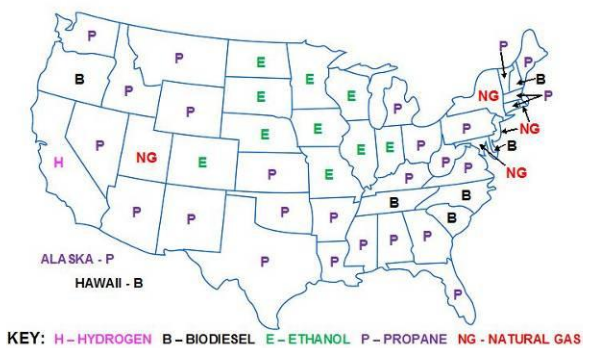

Figure 3. Map represents largest number of alternative fuel stations as of 2007 [32].

In addition, the modular design allows for flexibility when an interstate trip is required through the purchase and connection of a conventional gasoline or diesel generator to replace the alternative fuel version. This minimizes infrastructure limitations and allows freedom of movement for the consumer. Furthermore, planning is underway to make the vehicle energy neutral through next year's incorporation of plug-in battery recharging and a solar energy refueling station. The integration of solar energy is important because there is a clear and immediate need to get students working in this field to support the President's Solar America Initiative which seeks to make solar power cost-competitive with conventional forms of electricity by 2015 [33]. Moreover, companies and governments working to build electric vehicle refilling stations will need students who have this specific skill set [34-36]. Future efforts will incorporate wind energy into the filling station making this project even more relevant to ancillary vehicle technology development.

Economic Sustainability

The support of local energy markets directs this program towards Economic Sustainability, which is the union of people and prosperity. In Thomas Friedman's book [37], he quotes a South African Daimler ad for the Smart "ForFour"; "German Engineering, Swiss Innovation, American Nothing." America prides itself for being the best in the world, but the world does not always agree. Consequently, this project's support of the Energy Technology Revolution is increasingly important right here and now. As the Information Technology boom recedes and the financial markets are in recession, the Energy Technology Revolution may become the driving force for a new stable economy by building infrastructure, providing jobs and producing the goods and services required in the 21st century global economic landscape. Hence, as this project supports local energy markets, it supports local job growth, thereby increasing local and in turn national economic sustainability.

Therefore, it is important for students to work with the latest technological advancements, but with the recent economic downturn, this is not feasible on a large scale. Note for example, recent news articles illustrating that students at MIT spent $243,000 in building their solar energy racer [38] and students at Sakarya University spent $170,000 to build a fuel cell vehicle that competed in the Shell Eco-Marathon [39]. This is not an economically sustainable model of production without a large endowment and significant donations by alumni. In the case of smaller schools without such resources at hand, this model of collaborative student projects is unfeasible. However, recycling vehicles and incorporating advanced technologies wisely (e.g. reserving funding for an efficient drive motor by selecting cost effective lead-acid batteries) allows students to master the same design concepts but at a much more reasonable cost level. This will ensure that the students have the proper job skills to go out into the marketplace and lead the new wave of energy conscious engineers. In the Future Efforts section, the authors present a novel direction at KU that will reduce costs even further while increasing the level of technology of the program.

Educational Sustainability

Emboldened by a sense of responsibility for leadership of the Energy Technology Revolution, the fourth vector of success, Educational Sustainability combines the best aspects of people, planet and prosperity to drive the project onward. The students and faculty seek to build bridges between consumers, industry, academia and the engineers of tomorrow by fostering an open design environment, networking with everyone from hobbyists to experienced hybrid-electric drive experts, as well as crafting projects that raise awareness in all levels of education from grade school to post graduate.

Furthermore, the unique opportunities afforded by a university setting permit the gathering of many different talents under one roof. The School of Engineering brings the obvious Mechanical Engineers to the table, while additionally allowing for the incorporation of Aerospace Engineers (AE) to develop micro-turbine technologies and analyze aerodynamic drag effects in the wind tunnel. Chemical and Petroleum Engineers (C&PE) can develop advanced fuels for operation, and Electrical Engineers and Computer Scientists (EECS) can develop new even more efficient energy management systems. Moreover, by applying a feedstock to tailpipe approach, departments not commonly associated with engineering projects can become involved as Evolutionary Biologists work on algae for biofuel, Business majors work on overcoming market stigmas concerning electric drive systems, and Political Scientists work on the energy policies that will guide government interaction in the years to come.

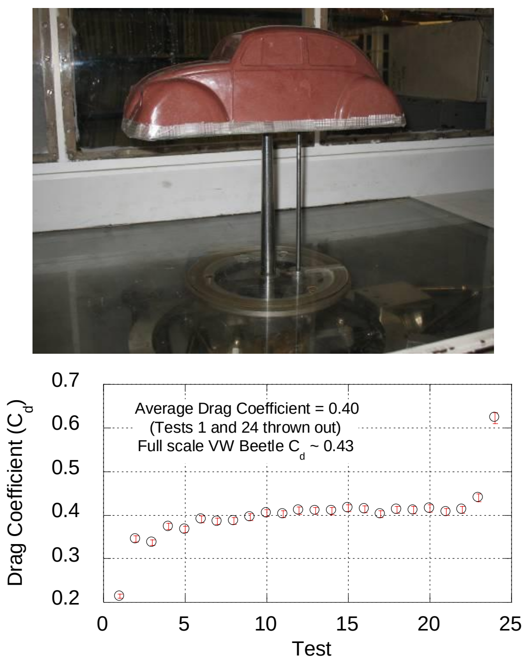

Figure 4. Small-scale drag testing in Aerospace wind tunnel.

The main author has already built multi-disciplinary relationships at KU as part of a Feedstock to Tailpipe© Initiative underway through the Transportation Research Institute and his efforts as part of a university wide Sustainability Working Group. Including other faculty in the EcoHawk efforts has been fundamental to its current and future success. In particular, KU's Biodiesel Initiative, overseen by a faculty member in C&PE, is creating the biodiesel to run in the vehicle [40]. The Aerospace department has generously donated space for the project, as well as, lent aid to scale drag calculations in their wind tunnel as illustrated in Figure 4. The main author helped oversee a team of students in the EECS department who completed regenerative braking on a Remote Control car in order to learn the principles to apply later on the larger scale. In addition, other faculty are expressing interest in helping out with the project and having students incorporate their own unique backgrounds into the efforts.

Ethical Sustainability

Ethical Sustainability looks to place design decisions in the larger social context so engineers can understand the wide-ranging impact of their decisions. For example, one argument under discussion is the "food for fuel" concept of biofuels with respect to the next generation of vehicles [41]. Governments are weighing the social requirements for cheap, eco-friendly fuels against the idea of creating these fuels out of protein rich foods such as soybeans. Incorporation of this concept and others into this project is intrinsic through the interdisciplinary Educational Sustainability focus under development. Having C&PE students interact with ME students fosters the discussion of the food for fuel argument involving multiple perspectives. As a result, the main author will require students to defend their decisions in the larger context and illustrate a sustainable approach to the vehicular industry that makes ethical sense. This will help engineers develop new technologies to address the problems faced by society.

In addition, students now have the option to interact with multiple disciplines to learn about viewpoints beyond their traditional subject area. For example, quite often ME students only understand the performance impact of their decisions with respect to hybrid vehicles. They want to make them faster, go further on a gallon of fuel and overall perform more efficiently. However, what often goes unnoticed is the tradeoff of fuel economy and hazardous emissions. As fuel economy goes up and the engine is getting more energy out of the fuel, the temperatures in the combustion chamber increase; the hotter the burn, the higher the pressure (ideal gas law) and the more force on the piston creating more power out of a fuel charge. The increase in temperature releases more nitrogen oxides into the atmosphere. By linking the ME vehicle build with an Environmental Engineering student emissions analysis, this concept becomes readily evident and the students gain a new perspective of their work. This raises an ethical question: What is more important, reducing greenhouse gas or hazardous emissions?

In addition, as the students strive to build increasingly efficient power plants, the cost of the vehicle increases. For a family living on the fringes of poverty who cannot afford a hybrid vehicle, another question results: Do they need an ultra-high fuel economy vehicle to reduce their yearly fuel costs or a cheaper, slightly less efficient version? Hence, through discussions and the generated data in the program, faculty can ask all of the same energy questions present in society and have the students start understanding the impact of their decisions.

As illustrated by the publicity gathered as part of the project, students are already learning about these questions beyond the classroom setting. Having questions asked by news and print reporters causes them to consider opinions differing from their own along with how their decisions play out in the court of public opinion. Thus, interactions with the public when promoting the program force students to defend their choices and require them to be aware of societal issues.

VISUAL ILLUSTRATION OF PROGRESS

This section illustrates to the reader the work required to recycle a vehicle and turn it into a series hybrid. This may help other faculty determine whether such an approach is desirable and feasible for their curriculum. The overall cost of retrofitting the vehicle was around $25,000 including tools, generators, batteries, speed controller, electric motor and all auxiliary items needed to start a program from scratch. With respect to just the biodiesel vehicle components, the price tag was around $15,000.

Figure 5. 1974 VW Super Beetle at Das Autohaus.

Figure 6. Vehicle was sandblasted to remove old paint.

Figure 7. Students worked to get exterior body into shape.

Figure 8. Vehicle was primed and moved into workspace.

Figure 9. Students test fitted components in vehicle.

Figure 10. Electric motor coupled to original transmission.

Figure 11. Suspension upgraded and disc brakes installed.

Figure 12. Interior cleaned and painted in preparation for final installation of components.

Figure 13. Battery boxes fabricated, batteries installed and connected in series.

Figure 14. Generator implemented to run 100% biodiesel recycled from used cooking oil in campus dining halls.

Figure 15. Gasoline generator being retrofitted to run on ethanol for eventual incorporation in vehicle.

Figure 16. Motor controller, battery charger installed and system wired.

Figure 17. Generator control moved inside the vehicle and gauges added.

Figure 18. KU EcoHawks successfully turn VW into a series hybrid vehicle [42].

Overall, the students proved their ability to create a series hybrid vehicle where the biodiesel IC engine recharges the batteries that power the electric motor. However, the students did not implement the E85 generator due to lack of time and issues involving modification of the gasoline fuel system. These modifications are feasible in the future and the students will eventually exchange the biodiesel generator to illustrate the flexibility of the range extender system. It is important to note that the ethanol generator is smaller than the biodiesel version; hence, there should be minimal installation problems.

FUTURE EFFORTS

As a first year project, the students were able to achieve a tremendous amount of work both from a theoretical understanding of the hybrid system along with a practical implementation. Initial theoretical calculations have shown that the vehicle should achieve around 50 mpg [43], well short of the intended goal but still an 80% increase in miles per gallon over the original design. Since the students started from square one and have maintained over a 3.0 GPA as a team, faculty have considered it a successful year. If the project was to start over again, a better tactic may have been to recycle the older vehicle into just an Electric Vehicle in the first year in order to reduce some complexity and ensure that the vehicle would be road ready.

As it stands, the second year of the project will be devoted to getting the vehicle on the road and driving around town to garner more publicity for the program, as well as highlight the sponsors. This will also provide the opportunity to take real world data and help the students start optimizing the control structure to increase the efficiency of the vehicle. In addition, 110 or 220V plug-in architecture will be included along with a solar energy filling station. Future efforts will continue to build on past knowledge until the time when students are able to design, fabricate and demonstrate a 500 mpg vehicle from scratch. In addition, the faculty will begin building a graduate level emphasis into the program in order to add a research component. Of importance, two EcoHawk students are staying for graduate school with one working under the primary author.

One unique avenue for next year is a more involved incorporation of Remote Control (RC) cars. As other faculty in different disciplines have shown interest in collaborating on the project, one common thread of concern permeated the discussion: "How and when would we have access to the vehicle?" In order for students to achieve their educational objectives, they must have unfettered access and be allowed time for implementation, testing and validation. However, cost and space limitations prohibit the building of multiple vehicles and, as a result, a significant amount of coordination would be required in order for all students to have access simultaneously to one prototype vehicle. Time constraints on faculty and students make this nearly impossible to achieve and inevitable student deadlines would cause friction between all members leading to a breakdown of the initial good will.

Hence, it became apparent that some other avenue of integrating all involved in building a high-efficiency vehicle is required. Faculty and students have built the framework of the EcoHawks, but the hurdles of cost, implementation and interdisciplinary objectives need further refinement. The idea of such a novel methodology occurred to the main author while attending a departmental faculty meeting. In specific, Remote Control (RC) vehicles provide a fun way of testing advanced concepts on a low cost basis along with adding more theoretical development into the program.

A recent comment in a ME faculty meeting by the department chair indicated that the perception of engineering by incoming students is that it is hard, rigorous and not fun; for example, only 35% of college students believe an engineering degree is worth the extra effort [16]. While unable to modify the difficulty level involved with coursework, the main author can effect change in reversing the idea of a boring and arduous environment. By building a sustainable, interdisciplinary framework at KU around RC vehicles, students in all disciplines can explore the limits of efficient vehicles in a low cost, fun and synergistic manner.

RC vehicles allow for a significant reduction in cost because of the relative scale of components (1:8/1:10), while also *increasing* the level of technology of the program. For example, brushless motors are priced at $100 allowing for around a 200-fold decrease in cost of the project (phone conversations with EV brushless motor manufacturers used as larger vehicle cost). In addition, Internal Combustion engines and even fuel cells are available permitting students to investigate advanced efficiency concepts without breaking the budget. Newer technologies are often more prevalent on a smaller scale basis again because of the relative cost of implementation. This empowers students to implement future technologies making them more attractive as engineers leaving the university.

Furthermore, this approach allows the faculty to adapt the curriculum according to any shift in national priorities. For example, in Innovate America, General Motors touted hydrogen fuel cells as a "fundamental opportunity" that they were investigating in response to the commitment of the Bush administration [22]; however, technological challenges and infrastructure limitations eventually killed this opportunity on a national level [44]. The small-scale experimentation available through the RC approach allows for a relatively easy shift to new prospects on a yearly basis in order to match the industry without throwing away a large investment in infrastructure and equipment. Ironically, the same Council on Competitiveness report mentions this adaptation to new opportunities as a focus for a competitive future.

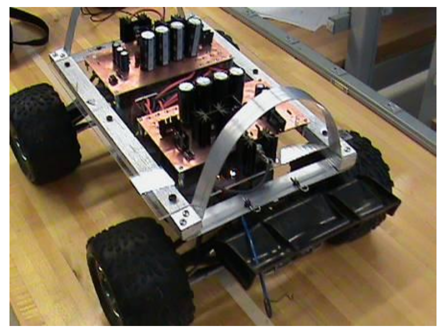

Figure 19. 2009 EECS students implementing regenerative braking on an RC car.

RC vehicles also help increase the implementation of new technologies by reducing the space requirements and allowing students more accessibility to their work. Instead of having to be present on campus to labor on a vehicle located at a singular point, the work is portable and allows more time for their efforts around their other classes. In addition, students can now afford the opportunity to try and fail with reduced ramifications. Because costs are relatively moderate, students can push the boundaries of efficiency to the *physical* limits of the technology instead of taking a conservative approach. Often, students learn more upon failing than by succeeding and the RC approach provides the ultimate teaching flexibility in this manner. Additionally, testing components to the point of failure indicates where improvements are needed to continue refinement on the technology. In fact, Sitkin mentions that encountering failure as a precursor to success is an *essential* part of the learning process [45].

Moreover, the use of RC vehicles increases the interdisciplinary nature of the program by creating independent projects with a common purpose. Instead of relying on one group to finish their tasks on a vehicle before another group can begin, each faculty member can have their own fleet of RC vehicles. The end goal of increased efficiency is the same; however, students can work at their own pace and not have to worry about being reliant on factors outside their control. For example, a group of EECS students at KU has already implemented regenerative braking on a RC car platform as shown in Figure 19. While working independently, the end goal of their efforts will eventually be employed in the cars built by the ME students after the EECS students test, debug and validate their tactics. Additionally, this provides a phasing of technology into the program before implementation on the bigger vehicle a tactic common to commercial design development. Through experimentation and modeling on the small scale, ideas can be refined and honed before the expenditures required for the larger scale making the program more efficient both from time and cost perspectives.

The idea of the RC approach is to allow each faculty member to explore the complex automotive system independently at first but with an eventual assimilation of technology. Students taking the ME design project will be simultaneously working on the larger vehicle. For example, one year on the larger vehicle might be dedicated to just implementing and optimizing the control of a high efficiency motor that was first accomplished via students using the RC framework.

Perhaps most important, RC vehicles provide a perfect medium for competition among departments and inclusion of K-12 students. National competitions always stimulate the enthusiasm of the student, but some come at the cost of neglecting other classes. Discussions with engineering faculty, here and at other universities, has indicated that the "need" to finish first in these competitions has caused students to miss graduation dates and make poor decisions regarding their coursework. Creating an in-house competitive environment would increase the excitement factor of engineering while remaining cognizant of the student's requirements for completing their other academic duties. In addition, as discussed in Educating the Engineer of 2020: "Engineering schools should lend their energies to a national effort to improve math, science, and engineering education at the K-12 level" [16]. This integration of K-12 education is inherently feasible because the vehicle build is manageable for younger students. Implementation of class divisions allow students to compete against their peers racing vehicles in fuel economy and performance tests [46]. This allows a direct linkage between younger and older students helping foster the development of future engineers. University sponsored events, like "race with the EcoHawks", would be a great way to make connections not available inside the classroom.

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