REQUEST FOR PROPOSALS

VEHICLE POWERTRAIN MODELING AND DESIGN PROBLEM

ECOCAR 3

A COLLEGIATE ADVANCED VEHICLE TECHNOLOGY COMPETITION

EXECUTIVE SUMMARY

Request for Proposals Issue Date	May 14, 2013
Submission Deadline for Proposals	December 9, 2013, at 4 p.m. Eastern Standard Time
Required Documents	1. Administrative Proposal (requirements listed in "Proposal Content & Outline" section, pages 18–24) with the following naming convention: UniversityName_EC3AdminProposal.pdf 2. Letter signed by the Dean of Engineering confirming the university support requirements (listed in the "Dean of Engineering Letter Content" section, page 23) with the following naming convention: UniversityName_EC3DeanLetter.pdf 3. Vehicle Powertrain Modeling and Design Problem Proposal submission (listed in a separate document found on www.avtchistory.org) with the following naming convention: UniversityName_EC3ModelingProposal.pdf
Means of Submission	An electronic PDF version of the administrative proposal, Dean's letter, and Vehicle Powertrain Modeling and Design Problem Proposal submission must be ***emailed*** **as three single files** to ***ecocar3@anl.gov***.
Anticipated Teams Accepted	Up to 17 teams
Eligibility	Schools must be accredited by the Accreditation Board for Engineering Technology (ABET) or the Canadian Engineering Accreditation Board (CEAB) or the Council of Accreditation of the Education of Engineering (CACEI) in Mexico.
Multiple Submissions	Only one proposal per school will be considered.

CONTENTS

Competition Overview

Since 1989, the U.S. Department of Energy (DOE) has been sponsoring advanced vehicle technology competitions (AVTCs) in partnership with the domestic automotive industry to stimulate the development and demonstration of advanced powertrain and alternative fuel technologies and to seed the automotive industry with thousands of graduates who have hands-on, real-world experience in advanced vehicle technologies. Argonne National Laboratory, a DOE research and development (R&D) facility, provides technical management of and has operational responsibilities for the AVTC Program. Most recently, *EcoCAR 2: Plugging In To The Future* (www.ecocar2.org) — a three-year competition started in 2011 and sponsored by DOE and General Motors (GM) — has given engineering schools an opportunity to participate in hands-on R&D, working with leading-edge automotive powertrain systems, fuels, materials, and emissions-control technologies by re-engineering a 2013 Chevrolet Malibu to minimize petroleum energy consumption, tailpipe emissions, and greenhouse gas (GHG) emissions while maintaining or exceeding the utility and performance of stock vehicles.

Argonne is seeking university participants for the EcoCAR 3 collegiate automotive engineering competition. DOE has partnered with GM on this new four-year competition series to give engineering students the chance to design and integrate advanced technology powertrains and controls into a production light-duty vehicle platform. The goal is to minimize the environmental impacts related to personal transportation vehicles and lead the way to a sustainable transportation future.

EcoCAR 3 will explore the same technologies that the automotive industry is investigating to improve energy efficiency and reduce GHGs. The *only* fuels approved for use in EcoCAR 3 are E10 gasoline, E85 ethanol, B20 biodiesel, and the energy carrier grid electricity. The technical goals for EcoCAR 3 are to construct and demonstrate vehicles and powertrains that accomplish the following in comparison to production gasoline vehicles:

- Reduce energy consumption
- Reduce well-to-wheel (WTW) GHG emissions
- Reduce criteria tailpipe emissions
- Maintain consumer acceptability in the areas of performance, utility, and safety
- Meet energy and environmental goals, while considering cost and innovation

Participation in EcoCAR 3 will be determined by this Request for Proposal (RFP) process, which is open to accredited[1] engineering schools in Canada, Mexico, and the United States. The organizers anticipate selecting up to 17 schools from North America to participate in EcoCAR 3. Student teams who wish to be considered for participation in the competition must solve several modeling problems and complete conceptual vehicle designs (requirements outlined in this document) as well as the administrative RFP. The organizers will then select schools for participation in EcoCAR

[1] Schools must be accredited by the Accreditation Board for Engineering Technology (ABET) or the Canadian Engineering Accreditation Board (CEAB) or he Council of Accreditation of the Education of Engineering (CACEI) in Mexico

3 on the basis of multiple factors, including the quality of the proposal, available facilities, level of school support, financial support, technical expertise, related competition vehicle experience, and geographic diversity. To be eligible for selection, teams must respond to the Administrative Proposal (located at www.avtchistory.org) as well as the Vehicle Powertrain Modeling Design Problem Proposal. The requirements for the Vehicle Powertrain Modeling Design Problem Proposal are detailed later in this document.

Modeling Problem Overview

The purpose of this document is to outline the AVTC's general modeling and design requirements, which will accurately reflect the activities that the students will carry out in EcoCAR 3. The competition will require students to have a unique understanding of the automotive engineering design process, which involves several factors, such as safety, performance, energy consumption, cost, innovation, and consumer appeal. The following sections outline several modeling problems that must be explained and addressed in a clear and concise format (per the following outline) to be reviewed by industry experts who are selecting the EcoCAR 3 teams.

The work required to address the modeling problems in this document can be incorporated into a new or existing undergraduate engineering course. The course should be aimed at a group of students and faculty advisors interested in understanding powertrain design and modeling at an appropriate level based on real-world design targets. Models should be developed with the appropriate fidelity to achieve the goals of the RFP, and applicants should consider the complexity of the model versus the required output. The results of the modeling and design activity will produce the content for this portion of the EcoCAR 3 proposal. Note that the exercises defined in this document require a substantial amount of work and cannot be completed in a matter of days by a single person. The competition organizers have made a set of self-paced educational resources available to the general public. These resources provide a foundation for modeling basic energy consumption, energy storage systems (ESSs), and hybrid supervisory controls. They can be found at www.avtchistory.org.

Performance and Utility Targets for the EcoCAR 3 Vehicle Modeling and Design Problem Proposal

The following minimum requirements for performance and utility are part of the EcoCAR 3 proposal process and therefore should be considered when vehicle configurations are being developed for this proposal. Although the performance and utility targets for the actual competition will not be finalized until after the EcoCAR 3 schools are selected, they will be comparable to these targets. The requirements here serve as guidelines for the report submission. The actual powertrain selection process will occur after the competition has begun, and it will be influenced by the final performance targets and the support available for sponsored components. Criteria (or regulated/tailpipe) emissions targets will be considered as part of the EcoCAR 3 competition but not specifically for this modeling problem.

Table 1: Vehicle Modeling and Design Targets

Performance/Utility Category	Vehicle Modeling Design Targets*
Energy consumption (unadjusted energy use on combined Federal Test Procedure [FTP] city and highway cycles)	Better than 370 Wh/km (600 Wh/mi) combined city and highway (55%/45%, respectively)
GHG emissions (WTW combined city and highway cycles)	Less than 120 g of carbon dioxide equivalent (CO_2 eq)/km (200 g CO_2 eq/mi)
Interior size/number of passengers	Minimum of four passengers
Luggage capacity	More than 230 L (8 ft^3)
Range	Greater than 320 km (200 mi) combined city and highway
Top speed	Greater than 135 kph (85 mph)
Acceleration time of 0 to 97 km per hour or kph (0 to 60 mi per hour or mph)	Less than 11 seconds
Highway gradeability (at gross vehicle weight rating [GVWR])	Greater than 3.5% grade at a constant 97 kph (60 mph) for 20 minutes

* The organizers reserve the right to change these requirements for the competition.

Vehicle Powertrain Modeling and Design Proposal Content, Outline, and Scoring

The EcoCAR 3 proposal process is broken down into two parts: the Administrative Proposal and the Vehicle Powertrain Modeling and Design Problem Proposal. The requirements for the Administrative Proposal can be found in a separate document at www.avtchistory.org. The outline for the Vehicle Powertrain Modeling Design Problem Proposal is summarized in Table 2, and full details are provided in the following sections. Templates are included for all tables and figures required by the proposal. Universities must follow this outline in their EcoCAR 3 Vehicle Powertrain Modeling Design Problem Proposal submission. Each proposal must include responses to all of the topics and must follow the format and structure provided, including the tables and figures where indicated. Additional information, tables, and figures may be included if desired. The Vehicle Powertrain Modeling Design Problem Proposal is limited to 30 pages, not including the title page, table of contents, and any appendices.

Table 2: Required Elements of the Vehicle Powertrain Modeling and Design Problem Proposal

Section	Scoring	Page Limit
Title Page	0%	No limit
Executive Summary	5%	1 page
Table of Contents	0%	No limit
Power and Energy Requirements at the Wheels	5%	30 pages
Conventional Vehicle Performance and Fuel Consumption	15%	
Battery Electric Vehicle Performance and Energy Consumption	15%	
Series Hybrid Electric Vehicle Performance and Energy Consumption	15%	
Innovative Technologies to Reduce Energy Consumption	10%	
Proposed Powertrain Design to Meet EcoCAR 3 Design Targets	25%	
Summary and Conclusions	5%	
References	5%	No limit
Appendices	0%	No limit

Title Page

The modeling portion of your proposal should include a title page that includes the name of the university and the names of all the persons who contributed to the proposal. Students should also indicate their expected date of graduation.

Executive Summary

In approximately 500 words, the executive summary should describe the results and conclusions reached in the modeling portion of your proposal

1. Power and Energy Requirements at the Wheels

Background

The first step in determining the energy consumption of a vehicle is to determine the energy required for the glider vehicle to complete a given drive cycle. Sometimes referred to as energy consumption at the wheels, this is the energy required to complete the drive cycle without consideration for powertrain losses.

Problem Statement

Using the vehicle characteristics provided in Table 3, which are typical of a compact sedan, determine the total energy used by the vehicle for positive and negative (braking) tractive effort at the wheels over the following 1-Hz drive cycles: urban dynamometer driving schedule (UDDS)[2], highway fuel economy test (HwFET), and US06. Also determine the average positive propulsion power (at the wheels), the peak power and tractive effort force output (at the wheels), and the percent idle time (when vehicle speed and acceleration are zero). Assume 0% grade for the drive schedule. Reference all data and equations used. A good source is SAE 2003-01-2070.[3]

Table 3: Vehicle Glider Characteristics

Vehicle equivalent test weight (U.S. Environmental Protection Agency [EPA] inertial weight class, including two people)	1,500 kg
GVWR	2,000 kg
Road load coefficients for equivalent test weight	F_0 = 120 N F_1 = 1.46 N/(m/s) F_2 = 0.42 N/(m/s)^2
Drag * Area, C_dA_f	0.75 m^2
Coefficient of rolling resistance, C_{rr}	0.009

The road load equation used is:

$$F_{Tr} = F_0 + F_1\, v + F_2\, v^2 + F_{inertial}$$

where F_{Tr} is the tractive effort force at the wheels (N), v is the vehicle speed (m/s), and $F_{inertial}$ is the inertial force due to acceleration (N). Inertial force is defined by the following equation:

$$F_{inertial} = m_i a$$

where m_i is the vehicle inertial mass (kg), including the inertia of rotating wheels, and a is the vehicle acceleration (m/s^2) ($\Delta v/\Delta t$ from the drive schedule). Note that the road load coefficients (F's) given are only for the given test weight, and they do not automatically scale with changes in vehicle weight.

An alternative road load equation[2] used is:

$$F_{Tr} = \text{mg}\, C_{rr} + \tfrac{1}{2}\, \rho\, C_dA_f\, v^2 + F_{inertial}$$

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[2] http://www.epa.gov/nvfel/testing/dynamometer.htm#vehcycles.

[3] Sovran, G., and D. Blaser, 2003, *A Contribution to Understanding Automotive Fuel Economy and Its Limits,* Technical Paper SAE 2003-01-2070, Society of Automotive Engineers, May 12.

Where m is the vehicle test mass in kg, g is the acceleration due to gravity (9.81 m/s^2), and ρ is the density of air (1.2 kg/m^3). The values of (Crr, C_dA_f) are equivalent to (F_0, F_1, F_2), and this form of the road load model scales with the vehicle weight.

Results for all three drive cycles (UDDS, HwFET, US06) must be summarized in the format described in Table 4.

Table 4: Template for Reporting Results at the Wheels for Drive Cycles

Metric	UDDS	HwFET	US06
Positive propulsion energy required at the wheels (Wh/km)			
Negative (braking) energy required at the wheels (Wh/km)			
Net (road load) energy required at the wheels (Wh/km)			
Average positive propulsion power at the wheels (kW)			
Peak power output at the wheels (kW)			
Peak tractive force at the wheels (kN)			
Percent idle time (%)			

In a separate table (like Table 5), estimate the average power at the wheels required to meet the minimum acceleration time. In the same table, determine the power at the wheels required to climb a 3.5% grade at 60 mph (97 kph) at the GVWR.

Table 5: Template for Reporting Average Power Results

Metric	Result
Average power required to meet minimum acceleration time (kW)	
Average power required to climb 3.5% grade at 60 mph at GVWR (kW)	

2. Conventional Vehicle Performance and Fuel Consumption

Background

A generic 100-kW (~1.8-L) gasoline-fueled engine has the power and efficiency characteristics listed in Table 6. A representative engine efficiency map is shown in Figure 1. Note that the shape of the wide-open throttle curve, constant efficiency lines, and relative position of the peak efficiency point are only meant to be representative. Your specific engine model will be different and should be documented as part of your report.

Table 6: Generic 100-kW Engine Parameters

T_b*	160 Nm
N*	6,000 rpm
P_b*	100 kW
$\eta_{b,\,max}$	35%

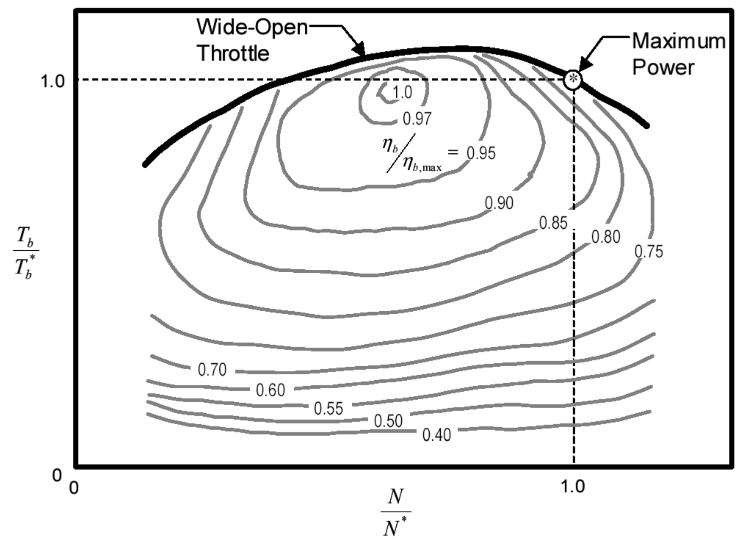

Figure 1: Representative Operating Map for a Gasoline Engine
(Source: Figure 7 from Sovran and Blazer 2003)

Problem Statement

Using this size and power gasoline engine, develop and document a model of a vehicle with a conventional powertrain using the vehicle glider characteristics just given. Also document the transmission model and gearing selected for the powertrain. Use Table 7: Template for Reporting Results and Powertrain Sizingto document critical powertrain and vehicle characteristics used in the model. Discuss the assumptions, limitations, and sensitivities of your model. Also include a diagram similar to Figure 2 that shows the powertrain configuration and power flow of your model.

Table 7: Template for Reporting Results and Powertrain Sizing

Test mass, kg	1500
Top speed, kph (mph)	
Acceleration 0–60 mph, s	
Highway gradeability at 60 mph at test mass, %	
Powertrain configuration	
Powertrain sizing:	
Engine peak power, kW	
Transmission, gearing	
(Others as needed)	

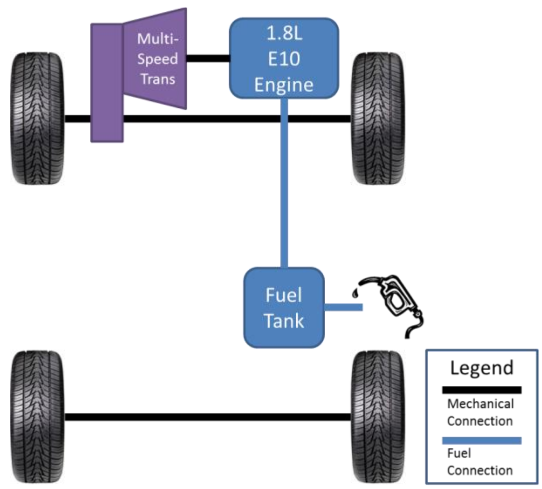

Figure 2: Template for Conventional Vehicle Powertrain Configuration and Power Flow

Model the vehicle performance and unadjusted fuel consumption over the three drive cycles at a test mass of 1,500 kg. Combined, unadjusted fuel consumption is a weighted sum of 55% UDDS and 45% HwFET results. Use Table 8: Template for Reporting Drive Cycle Energy Consumption Resultsto report the results of the model over the three drive cycles. Show an energy balance for your model to demonstrate that all fuel energy used over the drive cycle is consumed as losses in the powertrain, accessory load, and tractive energy out at the wheels. Based on the results of your model, answer the question "Is a conventional vehicle able to meet the fuel consumption target listed in Table 1?" Find a comparable conventional production vehicle in the EPA Test Car List data http://www.epa.gov/otaq/tcldata.htm and compare your modeled fuel consumption results with the unadjusted test data.

Table 8: Template for Reporting Drive Cycle Energy Consumption Results

Test Mass (kg): 1,500 Engine Size (kW): 100	**Unit**	**UDDS**	**HwFET**	**Combined**	**US06**
Net tractive energy	Wh/km				
Fuel energy	Wh/km				
Battery energy	DC Wh/km				
AC grid energy	AC Wh/km				
GHG WTW	g CO_2 eq/km				
Range	km				

Now revise your model to downsize the engine so that the vehicle just meets the minimum acceleration target. Use Table 9: Template for Reporting Drive Cycle Energy Consumption Resultsto report the results of the model over the three drive cycles. Also include a plot of fuel consumption versus acceleration time as engine size/power is varied (see Figure 3 for a template). Does this vehicle meet the fuel consumption target listed in Table 1? From your modeling, estimate the potential for fuel consumption reduction by using techniques such as "engine idle stop" and "decel fuel cutoff" (cutting off fuel during vehicle deceleration).

Table 9: Template for Reporting Drive Cycle Energy Consumption Results

Test Mass (kg): Engine Size (kW):	Unit	UDDS	HwFET	Combined	US06
Net tractive energy	Wh/km				
Fuel energy	Wh/km				
Battery energy	DC Wh/km				
AC grid energy	AC Wh/km				
GHG WTW	g CO_2 eq/km				
Range	km				

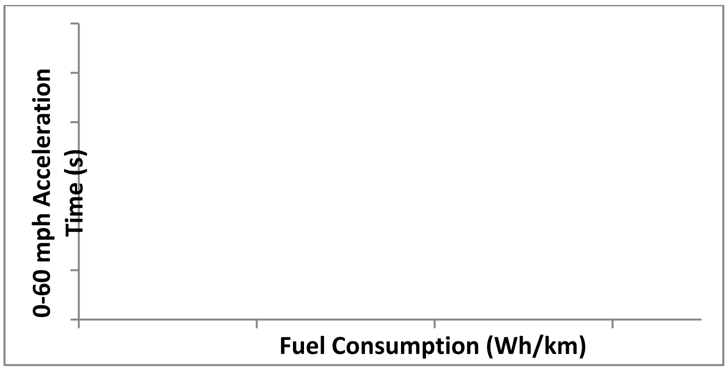

Figure 3: Template for Plotting Fuel Consumption Versus Acceleration for Varying Engine Size

Now modify your conventional powertrain model to use a diesel engine fueled by B20. Tune your model so that the acceleration time is equal to the first gasoline-powered conventional vehicle modeled. Document any changes to the engine efficiency model and transmission gearing. Use the templates provided in Table **10** and Table 11 to report the critical powertrain parameters and the results of the model over the three drive cycles. Compare the fuel consumption and WTW GHG emissions of the B20 and gasoline powertrains. Document the fuel properties used for the comparison. Teams are encouraged to evaluate their design on a WTW basis by using tools such as the GREET Model.

Table 10: Template for Reporting Results and Powertrain Sizing

Test mass, kg	1500
Top speed, kph (mph)	
Acceleration 0–60 mph, s	
Highway gradeability at 60 mph at test mass, %	
Powertrain configuration	
Powertrain sizing:	
Engine peak power, kW	
Transmission, gearing	
(Others as needed)	

Table 11: Template for Reporting Drive Cycle Energy Consumption Results

Test Mass (kg): Engine Size (kW):	Unit	UDDS	HwFET	Combined	US06
Net tract. energy	Wh/km				
Fuel energy	Wh/km				
Battery energy	DC Wh/km				
AC grid energy	AC Wh/km				
GHG WTW	g CO_2 eq/km				
Range	km				

3. Battery Electric Vehicle Performance and Energy Consumption

Background

One example of an advanced technology vehicle powertrain that could be proposed for EcoCAR 3 is a battery electric vehicle (BEV). This powertrain is relatively simple, it is easy to model, and it provides a foundation for further energy consumption modeling.

Problem Statement

Develop and document a model of a vehicle with an electric powertrain by using the glider vehicle characteristics from Table 1. Document the motor model and gearing selected for the powertrain. Develop and document a simple battery model that relates the battery size and mass to the power and energy available from the battery. Size the motor power (and thus the battery power) to meet or exceed the acceleration target, and size the battery energy capacity to meet the range requirement. Document how you estimate the mass of each component and total vehicle test mass. Use Table 12: Template for Reporting Results and Powertrain Sizing to document all critical powertrain and vehicle characteristics used in the model. Discuss the assumptions, limitations, and sensitivities of your model. Also include a diagram similar to Figure 4 that shows the powertrain configuration and power flow for your model.

Table 12: Template for Reporting Results and Powertrain Sizing

Test mass, kg	
Top speed, kph (mph)	
Acceleration 0–60 mph, s	
Highway gradeability at 60 mph at test mass, %	
Powertrain configuration	
Powertrain sizing:	
Motor peak power, kW	
Transmission, gearing	
Battery energy capacity, kWh	
Battery peak power, kW	
Battery mass, kg	
(Others as needed)	

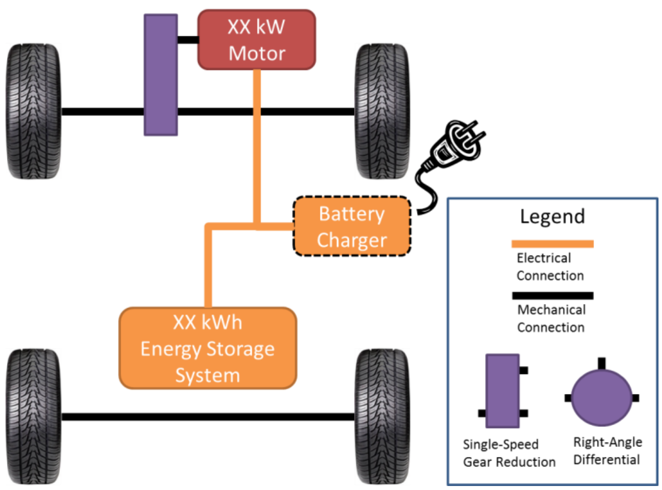

Figure 4: Template for Electric Vehicle Powertrain Configuration and Power Flow

Model the vehicle performance and energy consumption over the three drive cycles (UDDS, HwFET, and US06). Use Table 13: Template for Reporting Drive Cycle Energy Consumption Results to report the results of the model over the three drive cycles. Can the BEV meet the range requirement target and still remain under the GVWR while there are four people in the vehicle? Discuss the energy consumption and WTW GHG emissions of the BEV and compare them with those of a conventional vehicle. What is the impact of regenerative braking on range? Also show an energy balance for your model to demonstrate that all AC grid energy used over the drive cycle is consumed as losses in the powertrain, accessory load, and tractive energy out at the wheels. Does this energy balance validate your model?

Table 13: Template for Reporting Drive Cycle Energy Consumption Results

Test Mass (kg): 1,500 **Engine Size (kW): 100**	**Unit**	**UDDS**	**HwFET**	**Combined**	**US06**
Net tractive energy	Wh/km				
Fuel energy	Wh/km				
Battery energy	DC Wh/km				
AC grid energy	AC Wh/km				
GHG WTW	g CO_2 eq/km				
Range	km				

4. Series Hybrid Electric Vehicle Performance and Energy Consumption

Background

A series hybrid electric vehicle (HEV) is an example of a hybrid powertrain that could be proposed for EcoCAR 3. The BEV model can be used as a foundation for developing a model for this powertrain.

Problem Statement

Further develop the electric drive model to include an engine and generator to form a series HEV model. Document the engine-generator component model, and start with the 100-kW engine specified for the conventional vehicle in the previous section. Note that you will now need a hybrid vehicle supervisory control (HVSC) model to implement an energy management strategy and keep the battery state of charge (SOC) within reasonable bounds. Start with a relatively small battery with 3.0 kWh of total energy capacity and a maximum peak power of 50 kW. Document how you estimate the mass of each component as well as the total vehicle test mass. Use Table 14: Template for Reporting Results and Powertrain Sizing to document all critical powertrain and vehicle characteristics used in the model. Discuss the assumptions, limitations, and sensitivities of your model. Also include a diagram similar to Figure 2 and Figure 4 that shows the powertrain configuration and power flow for your model.

Table 14: Template for Reporting Results and Powertrain Sizing

Test mass, kg	
Top speed, kph (mph)	
Acceleration 0–60 mph, s	
Highway gradeability at 60 mph at test mass, %	
Powertrain configuration	
Powertrain sizing:	
Engine peak power, kW	
Generator peak power, kW	
Motor peak power, kW	
Transmission, gearing	
Battery energy capacity, kWh	
Battery peak power, kW	
Battery mass, kg	
(Others as needed)	

Model the vehicle performance and SOC balanced fuel consumption over the three drive cycles, starting with the 100-kW engine and 3.0-kWh/50-kW battery size. SOC balanced fuel consumption is defined as a net change in stored battery energy equal to less than 1% of the fuel energy used over a drive cycle. Use Table 15: Template for Reporting Drive Cycle Energy Consumption Results to report the results of the model over the three drive cycles. Investigate losses and fuel consumption for different energy management strategies, such as engine on/off (thermostatic) and load-following strategies. Document all of the component losses and show an energy balance from the fuel energy to the wheels of the vehicle for one example drive cycle. Does this energy balance validate your model?

Table 15: Template for Reporting Drive Cycle Energy Consumption Results

Test mass (kg): 1,500 Engine Size (kW): 100	Units	UDDS	HwFET	Combined	US06
Net tractive energy	Wh/km				
Fuel energy	Wh/km				
Battery energy	DC Wh/km				
AC grid energy	AC Wh/km				
GHG WTW	g CO_2 eq/km				
Range	km				

Now design a series HEV by sizing the battery and engine-generator to meet as many of the design targets as possible. Use Table 16: Template for Reporting Results and Powertrain Sizing to document all critical powertrain and vehicle characteristics used in the design. Pay particular attention to the continuous power requirements of the generator for highway gradeability and to the impacts of your energy management strategy. Discuss the trade-offs between battery sizing, mass, and losses versus engine-generator losses.

Table 16: Template for Reporting Results and Powertrain Sizing

Test mass, kg	
Top speed, kph (mph)	
Acceleration 0–60 mph, s	
Highway gradeability at 60 mph at test mass, %	
Powertrain configuration	
Powertrain sizing:	
Engine peak power, kW	
Generator peak power, kW	
Motor peak power, kW	
Transmission, gearing	
Battery energy capacity, kWh	
Battery peak power, kW	
Battery mass, kg	
(Others as needed)	

5. Innovative Technologies to Reduce Energy Consumption

Background

There are many innovative technologies that have the potential to reduce vehicle energy consumption. The exploration and implementation of these technologies will be encouraged in EcoCAR 3.

Problem Statement

Perform a short, focused literature search for information on these technologies, excluding powertrain electrification, aerodynamic and tire improvements, and vehicle structure light-weighting. Select <u>one</u> of these technologies, and then investigate its impact on fuel consumption by extending your conventional vehicle model. Consider the mass added by the technology and any aero drag increase. Report the model results for the technology and compare those data to the data from a conventional vehicle model, focusing on changes in losses. Is there a potential to meet the fuel consumption target by combining these technologies?

6. Proposed Powertrain Design to Meet EcoCAR 3 Design Targets

Background

The EcoCAR 3 competition is founded on a vehicle development process that requires teams to follow through on a powertrain design selected in Year One of the competition. All teams will be required to explore and model various powertrain configurations and ultimately select a powertrain for the duration of the competition.

Problem Statement

The model development and the results presented in the previous sections should give you some insight into the trade-offs with regard to component sizing, mass, performance, energy consumption, and losses. Based on this information and the knowledge you gained, design and document three different vehicle/fuel powertrains that could meet or exceed the design targets.

Show design alternatives and discuss the trade-offs you considered when making design decisions. Throughout your design process, consider the incremental cost increase that results from implementing advanced technologies in a vehicle. For example, how much more would a consumer expect to pay for the proposed vehicle over a conventional version? Discuss tradeoffs in design to account for the cost of implementing advanced technologies. Discuss any unique innovative aspects of or considerations associated with your designs. For each powertrain, provide the following tables and figures:

1. A summary table of critical powertrain and vehicle characteristics. Use Table 16 as a template.
2. A diagram to illustrate the powertrain configuration and power flow, similar to Figure 2 and Figure 4.
3. A summary table of how the powertrain compares against the design targets presented in Table 1.
4. A summary table documenting the drive cycle modeling results. Use Table 15 as a template.

Documentation of the detailed results of each design may be included in an appendix.

Propose a design that meets the target criteria of Table 1 that you think your team would like to build during EcoCAR 3. Discuss how your proposed vehicle would address each of the design requirements presented in this proposal, including acceleration, gradeability, energy consumption, WTW GHG emissions (g/km), and range. Specify the fuels and/or energy carriers you would use and why. Define all of the components, and report your results in the tables and figures described by using a format and layout similar to those used in previous sections. Be specific about SOC balanced (charge-sustaining) fuel consumption and about any AC grid (charge-depleting) energy use, if applicable. Propose a preferred powertrain design and provide reasons for your final selections. Consider the size/mass and integration of components into a compact sedan, as well as consumer appeal. Also consider the cost and availability of the components you have selected. Discuss how you modeled the energy management/control strategy in basic terms. Reference all data and equations used.

While no detailed modeling of exhaust emissions is needed, you should understand some of the constraints. High engine loading of a down-sized engine can be good for fuel efficiency, but this loading can also affect exhaust emissions, particularly nitrogen oxides (NO_x). Discuss at a high level any consideration of tailpipe emissions and any tradeoffs made in your design.

Summary and Conclusions

Provide an overview of your model development and results. Are your results useful for powertrain design considering the limitations of your models? What have you learned? Summarize your final energy source and vehicle powertrain design selections. Also summarize the tradeoffs made with respect to cost and innovation for your final powertrain design. Tell the proposal reviewers how this report demonstrates that your team should be selected to participate in EcoCAR 3.

References

Include citations for any textbooks, conference papers, journals, etc. that you used to develop this proposal.

BIBLIOGRAPHY

Applicants may find the following references useful when developing material for this proposal. This list is not comprehensive, and applicants should supplement this bibliography with their own literature review. This section is not one of those required for the proposal.

1. *Hybrid Electric Vehicles: Principles and Applications with Practical Perspectives*
   by Chris Mi, M. Abul Masrur, and David Wenzhong Gao, 2011.
2. *Electric and Hybrid Vehicles: Design Fundamentals,* Second Edition
   by Iqbal Husain, 2011.
3. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design*
   by Mehrdad Ehsani, Yimin Gao, and Ali Emadi, 2010.
4. *Propulsion Systems for Hybrid Vehicles,* Second Edition
   by John M. Miller, 2010.
5. *Electric Vehicle Technology Explained,* Second Edition
   by James Larminie, John Lowry, 2012.
6. *Vehicle Propulsion Systems: Introduction to Modeling and Optimization,* Second Edition
   by L. Guzzella and Antonio Sciarretta, 2007.
7. *Vehicle Power Management : Modeling, Control and Optimization*
   by Xi Zhang and Chris Mi, 2011.
8. Vehicle Powertrain Systems
   by Behrooz Mashadi and David Crolla, 2012.