Abstract
The University of Wisconsin – Madison Hybrid Vehicle Team has designed a series-parallel plug-in hybrid-electric system to implement in a stock Saturn Vue as per the requirements for the first year of the EcoCar competition. This design utilizes a 45 Ah battery pack and a 150 kW electric motor for up to 40 miles of local commuting. For extended trips, a 70 kW internal combustion engine will provide power at highway speeds. This engine will also be coupled to a generator for load leveling. The controls code has been written using MATLAB Simulink and verified on a National Instruments PXI chassis. All systems went through an extensive modeling process in CAD, PSAT and other mathematical simulation environments. MATLAB and National Instruments, competition sponsors, have donated the required software and hardware necessary for the complete Hardware-in-the-Loop simulation of Wisconsin’s EcoCar competition vehicle.

Use of EcoCAR Development Process
Wisconsin followed the EcoCAR Vehicle Development Process (VDP) while planning and developing for Wisconsin’s EcoCAR Challenge entry. The VDP is a timeline of goals for papers and workshops so proper analysis, modeling, and planning are done before work on hardware begins. The focus of the EcoCAR VDP is advanced powertrain development. Additionally, the EcoCAR VDP emphasizes communication between design subgroups and suggests a timeline for the work done by each subgroup.

Wisconsin’s vehicle development is divided into different weekly meetings for each subgroup to work on the upcoming goals of the EcoCAR VDP. Monday is an organizational and Energy Storage System (ESS) development day, where the team leaders meet and discuss the current week’s objectives and the electrical group works on the ESS design. The overall objective for the electrical group is to specify the vehicle ESS requirements and determine which available system is the best fit for the vehicle.

Tuesday evenings are dedicated to mechanical and outreach meetings. Early in the VDP process the mechanical members focus on architecture selection and major component testing and design. The mechanical team tested all of the architectures in Powertrain Systems Analysis Toolkit (PSAT), from Argonne National Laboratory. The modeled architectures were tested against the Vehicle Technical Specifications (VTS) which serve as overarching goals for the competition vehicle. Additionally, the team must balance VTS goals with packaging constraints, vehicle dynamic characteristics and maintaining a low center of gravity for handling performance. The outreach meetings are also held on Tuesdays, where community activities are planned and outreach events coordinated. Additionally, the outreach team is responsible for maintaining the team website, creating logos, branding, and team shirts. Outreach also serves as a corporate contact for sponsors and industry mentors.

Wednesday is used for controls meetings where development on vehicle component models, Hardware In the Loop simulation (HIL), and the vehicle electrical systems are accomplished. The controls team has created MATLAB Simulink models for each major component. These models are then implemented into the HIL simulations, allowing for a realistic testing environment to determine vehicle performance and system response prior to vehicle construction. This VTS step is critical in working out potential flaws in vehicle controls prior to construction.

Finally, on Friday Wisconsin holds a full team meeting to discuss the progress of each group on their respective tasks. This meeting ensures that each team has a time to interact with the other groups to keep everyone on task with progress and requirements to move forward in the competition. The EcoCAR VDP keeps Wisconsin on task with the various deadlines in the EcoCAR competition,
providing a framework for the vehicle development process.

**Powertrain Configuration**

Wisconsin aims for vehicle performance, sustainability, and versatility in selecting a parallel-series powertrain configuration. Coupling a Weber MPE750 70kW ethanol powered Internal Combustion Engine (ICE) with a 150 kW Continental Sapphire electric drive and a Delphi DU174 100 kW generator/assist motor, Wisconsin seeks to improve the fuel economy without sacrificing any performance, versatility, or ride comfort. Wisconsin will also utilize a CAN enabled Brusa 3 kW AC-DC charger to enable plug-in overnight charging, combined with a Johnson Controls-SAFT VL45E 45 Amp-hour 302.4 volt Lithium Ion battery pack will allow for 40 miles of charge depleting operation.

To achieve a high level of petroleum independence, Wisconsin has chosen to use a Plug in Hybrid Electric Vehicle (PHEV) design with charge sustaining and depleting control strategy. The large liquid cooled 45Ah battery pack was specified to provide enough energy without excessive weight or bulk in the vehicle to allow for long range electric only operation of the 1961 kg vehicle. Additionally, through US06, UDDS, and HWFET modeling runs in PSAT, Wisconsin observed the need for a battery pack with capacity greater than 40 Ah from peak and sustained cycle demands. Finally, this pack allows Wisconsin to achieve another VTS goal of 30 miles of electric only operation on a single charge.

Although the JCS VL45E battery pack allows Wisconsin to achieve a 30 mile EV only goal, it does not allow the vehicle to attain the 200 mile overall vehicle range. To achieve this goal, Wisconsin will implement a Delphi DU174 generator in charge-sustaining operation. The DU174 was chosen because of its large peak output of 105kW and optimal power to weight ratio. Using the DU174 clutched to the Weber MPE750 allows for both generation and electric assist under heavy load, this configuration allows for both high performance and high efficiency regeneration.

The primary electric motor in the vehicle design is a Continental Sapphire 150 kW peak electric motor with a 10:1 total gear reduction. Both the Sapphire and DU174 will boost consumer acceptability of the vehicle through the available low-end torque. Additionally, the Sapphire series-parallel design allows Wisconsin to surpass its acceleration VTS goals of under 10 seconds in 0-60mph and 5 seconds in 50-70mph trials. PSAT modeling indicate that Wisconsin will achieve 7.95 seconds and 3.25 seconds in 0-60mph and 50-70mph accelerations respectively. This component configuration will provide superb performance and result in achievement of greater than 1500 lbs towing capacity in accordance with our VTS goal.

While providing impressive performance, the efficiency of the electric motors is not ideal at highway speeds. Therefore, Wisconsin will implement a Weber MPE750 as genset as well as a primary drive at highway speeds. The MPE750 weighs only 50 kg and offers 70 kW of power and 131 Nm of torque. The MPE750 will maintain a high power to weight ratio while providing sufficient power required by the PSAT US06 cycle.

To power the MPE750, Wisconsin has chosen E85 to reduce its petroleum usage as per its VTS goals. Hydrogen was not available because Wisconsin does not have the facilities necessary for a hydrogen source. Although Wisconsin has extensive past experience with B20, E85 is more widely available in the United States and has lower environmental impact. Proper implementation of the MPE750 will permit Wisconsin to achieve a VTS emissions goal of a tier 2 bin 5 classification.

Wisconsin's VTS goals will not sacrifice performance or consumer acceptability in its split-parallel design. Through this configuration and selection of components, Wisconsin will create a more fuel-efficient vehicle with more performance, faster acceleration, equivalent handling and equal towing capacity.
Control Development Process

Wisconsin has implemented the V-diagram control development strategy shown in Figure 1. This process is effective in breaking down broad design goals into smaller subsystems and validating that these subsystems work together to achieve the high level design objectives. This method provides excellent design feedback and is a proven structure for vehicle development.

![V - Diagram](image)

**Figure 1: Tools needed throughout the development process**

The first step in the V-diagram requires a top-level definition of what Wisconsin’s control system requirements will be, as shown in Figure 1. The primary requirement is achieving the VTS goals in a manner that is safe to the passengers and the vehicle. Wisconsin is in the process of defining the requirements from each subsystem of the vehicle. The subsystems are the Weber MPE750 Engine Control Unit (ECU), the DU174 generator controller unit, the Sapphire controller, and the Battery Management System (BMS). These subsystems will be controlled by the Vehicle Control Unit (VCU) at the highest level with the goals of efficiency, safety, and drivability.

After the basic system requirements are specified, the control system architecture must be defined. Wisconsin has utilized high level logic diagrams to characterize the control system architecture. Modes of operation were defined through logic diagrams along with characteristics of each mode. Important characteristics of each mode include battery and coupling controls. The battery can be used in charge sustaining or charge depleting mode. The coupling of the generator must also be controlled to determine if a series or parallel powertrain is being utilized. Also, the controller hierarchy was determined using the VCU as part of the HIL while all other controllers will be absorbed within higher level plant models.

In the next state of the process, high level algorithm development was completed as well as determining the hierarchy of logic flow between each controller. Once the higher level logic was determined, the control strategy was developed using MATLAB Simulink in the algorithm and software design phase. In this stage, logic was be developed within individual MATLAB Simulink blocks and implemented as either mathematical functions or as state machines. Meticulous organization and testing of the system is necessary to verify the algorithm’s logic is correct. This verification is nearly complete and testing will continue as the logic and code is expanded.

With the use of MATLAB Simulink and MotoHawk suite, the software implementation step is no longer a time-consuming. Once the algorithm and software design is complete and verified, MATLAB and MotoHawk will automatically develop code from the symbolic controls logic developed in Simulink. This greatly reduces the time needed to verify the actual software implementation of the control strategy.

Following the V-diagram, each step of the design process is validated to confirm that the system achieves the overall goals. In the unit test stage, all computer models and software must be validated. This stage will first apply to the lowest level control within the VCU and will progress to the highest software levels. Most importantly, this validation confirms the code determines the correct mode of operation given simulated inputs. Once the code is tested and functions correctly, it can be integrated into the HIL setup and continue through the steps outlined in the V-diagram.

The next step is the unit behavioral test, which is where software in the loop (SIL) will be employed to validate the logic outlined in the algorithm software
design section. In this step, plant models were developed in Simulink using MATLAB's SimScape program, enabling Wisconsin to generate models based on experimental data. Lookup tables were integrated into the vehicle's control algorithm to calculate the car's response in areas such as efficiency, fuel economy, acceleration, and torque output. These plants were linked to their corresponding subsystem controller and then given simulated inputs to validate subsystem functionality. Wisconsin currently has working models for the Weber MPE750 engine, Sapphire, Delphi DU174 generator, and JCS battery pack, but is in the process of refining them for more accurate response data.

Validating the controller system as a whole is the next level of the V-diagram. HIL will be utilized to validate the algorithm requirements and will culminate the design process thus far. At this stage, the individual subsystems will be integrated into a single vehicle model. Validation of the controller system will include wiring the vehicle controllers to the NI PXI system, simulating driver inputs, testing vehicle plant outputs, and finalizing controller inputs and outputs.

Since this is the first series hybrid vehicle Wisconsin has constructed in over 10 years, the HIL will be particularly useful for initial functionality checks. The algorithms are being implemented into PSAT which is then used for fuel economy and acceleration runs. Besides checking for appropriate operation, the different algorithms can also be graded on fuel economy and acceleration improvements. The Simulink models can then be directly implemented into the HIL system.

The final step of the V-diagram, to be completed in Year 2 of competition, is to calibrate the control system using MotoTune and finally to validate the control system with the Saturn Vue. At this stage, the strategy needs to be adjusted to compensate for difference between the modeled systems and physical parameters. The vehicle's plug-in ability will also be tested and refined at this point. This step will complete the development process outlined by the V-diagram.

Control System Architecture

In order to meet Wisconsin's control architecture standards, it is essential that the controller boots up within seconds and that it is able to execute the entire control loop at a frequency of 200 Hz to ensure detection of high frequency system behaviors. These considerations will ensure a quick start up and smooth vehicle performance, which are required to meet consumer demands. The controller must also be able to withstand extreme engine bay conditions. Wisconsin decided on the MotoTron MPC5554 to best fulfill these requirements.

While considering controller options, Wisconsin also analyzed products available from dSPACE and National Instruments. The CompactRIO controller offered by National Instruments is capable of complex control code. It has equivalent input and output of other controllers as well as the support of the LabVIEW programming interface. However, this controller will not fit Wisconsin's needs since it is not suited for automotive applications. According to a National Instruments representative, it has a slow boot time and would require additional hardware to get the vehicle online in a reasonable amount of time. This unit is also open to outside elements and has a relatively high susceptibility to water damage.

The other controller option considered was the dSPACE MicroAutoBox. This unit is designed for the automotive industry. It is sealed and suitable for mounting within the engine bay. However, because the dSPACE controller has no practical advantages over the MotoTron controller, it is best to remain with the MotoTron MPC5554, with which Wisconsin has over eight years of successful working experience.

The MotoTron MPC5554 is a small upgrade for Wisconsin over the MotoTron MPC555 that has been used for the previous eight years by Wisconsin. The main advantages of using the new MPC5554 controller are that the MPC5554 offers two times the processing speed of MPC555 controller, 22 more input and output pins, the capability to use 3 CAN busses, and a much larger internal flash memory.
The MPC5554 has 33 analog inputs, 3 speed (digital) inputs, 14 low side driver power outputs, a 2 M internal flash memory, and triple 2.0B CAN interfaces which more than satisfy all design requirements.

The MPC5554 controller offers Wisconsin 5 times the performance of it’s predecessor as well as satisfying Wisconsin’s requirements for environmental conditions. The controller is cast aluminum and can withstand temperature changes from -45 °C to 105 °C.

The MPC5554 controller will be mounted in the engine bay and communicate with all other components via CAN messaging, more specifically on CAN1. The specific components communicating on CAN1 besides the MPC5554 controller will be the Sapphire controller, the Delphi DU 174 generator controller, and the JCS battery management system as shown in Figure 1: Tools needed throughout the development process Figure 2. The controller will send messages to these components in a continuous feedback loop. In essence, the controller will send out demands to each of the components and the components will send information based upon their performance back to the MPC5554 controller. The demands will be analog inputs from the driver such as pedal position, which is the processed by the controller. Digital signals from the shaft encoders, clutches, and other components will then be sent to the controller, then the code created by Wisconsin to run the car will send out proper demands to each component.

**Figure 2: Control architecture with components**

The Weber MPE750 will be controlled using the same MPC5554 controller yet will be treated as its own control unit. Engine code for the Weber MPE750 has been developed over the past few years in cooperation with the University of Wisconsin SAE Clean Snowmobile Team. This code allows the engine to run on E85 operating in an integral PID closed loop heated oxygen sensor algorithm for additional emissions reductions. Wisconsin will revalidate emissions after the engine and exhaust system have been integrated into the stock Saturn Vue. Once this code is implemented within the controller, the engine control will be abstracted to simple torque and speed requests.

The stock components in the car will communicate via CAN2 or GMLAN. CAN2 will relay messages from the controller to the dashboard to ensure the dials are outputting the proper values. A possible use for CAN3 will be to communicate from the MotoTron MPC5554 controller to a FreeScale touch screen in the dashboard of the car. The touch screen will be able to send calibration information to the VCU as well as receive and display the code as it runs on the car. This touch screen will provide instant access to control information and help Wisconsin to discover possible errors, maximize efficiency, and provide an instructive tool to new team members and the public.

This idea of abstraction is common throughout Wisconsin’s control architecture. It allows the hybrid control to operate at a high level using torque and speed requests. The VCU is designed within the limits of the system it is controlling; however, if a system were to go unchecked, the low level controller will also have embedded safety algorithm. Redundancy lowers the DFMEA frequency score since these limits are actually checked multiple times on multiple systems. This system is used throughout the controller network and will be present on the Vue through all control system interaction.
Control Algorithm and Strategy

The inputs that will relay their current states to the VCU via CAN messaging are the Weber MPE750, the Sapphire, the MotoTron PIM, the JCS Battery, and GMLAN. Once these inputs are relayed to the VCU they must be converted from computer language CAN messages into engineering units that will be analyzed by the vehicle control algorithms. These inputs will determine the control state and will broadcast corresponding commands to each of the subsystems.

To operate the vehicle safely and effectively, the control strategy will be designed to function in five states. These states will include modes for charge-depleting, extended-range charge sustaining, parallel coupled to the road, plug-in stationary charge, and safety fault mode as pictured in Figure 3. The control strategy will be designed to only allow operation in one discrete state at a time and will change the parameters and available outputs based on this state.

Under normal short-range operation, the owner will recharge the battery pack at home and the vehicle will consume battery energy while operating as an electric vehicle. When the battery state of charge reaches a predetermined lower limit (i.e. 25% SOC), the VCU will start the engine and the generator will operate until the batteries have been charged to another predetermined SOC (i.e. 95% SOC). The generator will not charge the lithium-ion batteries completely since we want to stay within the optimal range of 25-95% SOC and maximize ‘wall-plug’ usage.

The extended-range hybrid state uses the same powertrain as the charge-depleting state with the addition of the ICE and Delphi DU174 combination generator system. The engine and motor will be set to a constant optimal efficient torque demand level based upon testing and calibrations. The duration of this state will be dependent on the SOC of the battery; once the battery reaches the maximum recharge level the vehicle will exit the extended-range mode and return to default charge-depleting operation.

Since electric motors are inherently inefficient torque-coupling devices during high-speed operation, Wisconsin will be engineering a clutch to couple the ICE to the road. This state will require a complete change in powertrain from previously described states. To operate in this condition the vehicle will need to be traveling at nearly fifty miles per hour for a significant duration of time. Once it is detected that the vehicle is driving at highway speeds, the ICE will be started and speed-matched via encoders to the vehicle axle rotation. The drive shaft will then couple with the axle through a clutch controlled by the VCU, and the ICE will thereby be the primary traction source. Since the Delphi DU174 will still be coupled to the Weber MPE750, electric assist will be provided to the ICE. The set gear ratio

Figure 3: Controls algorithm strategy

If the high voltage battery is above a minimum threshold State of Charge (SOC), the default state upon starting the vehicle will be charge-depleting. In this state, the VCU will use the Sapphire in combination with the JCS Battery. Torque demands derived from driver pedal position will be processed directly through a torque map to an output for the Sapphire. This map will be calibrated to provide a responsive but efficient torque output that facilitates enjoyable driving. This calibration will also help meet the VTS goals for acceleration and towing. These goals include improving the stock 0-60 time and having a minimum 1500 lb towing capacity.
on the ICE only allows for high vehicle speed operation. This mode will be disabled once the vehicle slows to a speed below the efficient range of the engine.

In addition to designing control strategies for different driving states, Wisconsin will implement a simple method of charging the high voltage battery pack when the vehicle is not in use. Since this vehicle is not designed to be a charge sustaining hybrid, it is most efficient to begin every drive cycle with a fully-charged battery pack. The Brusa charger has its own on-board processor that will be programmed for use with the JCS battery system. The Brusa has CAN capability and the BMS will supply battery temperatures and limits which will be used to determine maximum charge rates. The charge process will be automatically controlled by the VCU instead of manually by the consumer.

When a powertrain problem arises or a device is malfunctioning, the code will attempt to isolate the faulty component from the rest of the vehicle and alert the driver. For instance, if there is a problem with the Delphi the vehicle would not be allowed to operate in the series state and the check hybrid/engine light would be lit. However, if the problem is extensive, the vehicle will fault to a safety shutdown state. This state will allow the components of the vehicle to remain online but only for calibration and debugging purposes. This state will be displayed by an indicator light on the dashboard and none of the driver inputs will have the ability to signal the components directly. Instead, a default safety calibration will be enacted, setting all values to zero or no response.

To control levels of maximum current to the battery, Wisconsin will actively monitor how much current is being produced and consumed by each individual electrical component. The maximum current limit to the battery would be attained when the vehicle is in the extended range mode and the regenerative brakes are applied. If the VCU calculates the regenerative braking maneuver combined with the generator will produce a higher current than the battery can accept, the Weber MPE750 and Delphi DU174 will be limited or completely disabled to maximize the energy recaptured from braking. When normal operation resumes, the generator will be reset to the previous torque levels. If necessary, current from the Sapphire will be limited only after the Delphi DU174 is completely disabled.

For control strategies, outputs must be sent from the VCU to each of the subsystems in the car. In this process, engineering units (i.e. rpm) must be converted back into CAN messages, and the VCU subsequently sends out its demands to the specified subsystems controller. These demands will control subsystems like the Weber MPE750 and the Delphi DU174 by requesting certain data from these systems. The output messages represent the control strategy finally being sent out to each of the components in the car. The control process will loop through this entire procedure every five milliseconds. At this rate, output values can be calculated fast enough so that the driver experiences smooth operation.

Packaging and Integration

The integration of major components proved to be a challenge since all components, the Sapphire, the Weber MPE750 engine, and the Delphi DU174, could not all fit within the engine compartment as originally thought. Given the size of the Sapphire, packaging options were limited to the engine compartment. Unfortunately, the Delphi DU174, shown in Figure 5, will not fit in the engine bay, as determined through CAD modeling. Wisconsin will package the Delphi DU174 under the middle console in between the front driver and passenger seats. This positioning could lead to noise and vibrations; however, proper mounting and insulation will reduce this effect. Also, the overall vehicle NVH will be quieter and smoother than the stock Vue due to a smaller engine.
New mounts will have to be designed for the DU174, Weber MPE750, Sapphire, and the battery pack. The design of these mounts will have to go through a waiver process and pass FEA analysis. Figure 6 shows how the Weber MPE750 and Sapphire mount to the front subframe.

The Weber MPE750 was an ideal choice for the IC engine because compact size and impressive power to weight ratios. A logical choice for a generator coupled to the Weber MPE750 would be a motor with similar specifications in power. Knowing Wisconsin had access to and significant experience with the DU174 motor, and given its small size made this motor perfect for use as a generator for the Vue. Since Wisconsin chose an electric drive as the primary power output for the Vue, a motor with enough power output to move the Vue was required. The Sapphire was an ideal choice because of its impressive output and efficiency. A battery pack with a high enough energy density was chosen in order to sustain driving with the power consumption of the Sapphire. This battery pack is being designed and donated by Johnson Controls-SAFT to meet the Sapphire requirements. This battery pack is expected to output 60 kW peak and 30 kW continuous.

The aerodynamic improvements planned for the Vue were negated once the 2-Mode Hybrid Vue was established as the competition donated vehicle, and only the plan to shrink or remove the side rear-view mirrors remains. A weight reduction of the subframe by replacement with an aluminum subframe is still being considered.

Problems arising from packaging components made the possibility of a very unique drivetrain setup. The ability for the Weber MPE750 coupled to the Delphi DU174 to be used as a generator or coupled to the rear differential to power the rear wheels makes this design unique. The engagement and disengagement of this system is a critical aspect of Wisconsin’s hybrid vehicle. Special consideration needed to be taken when choosing the appropriate clutch system between the Weber MPE750 and the Delphi DU174 and between the Delphi DU174 and the rear differential. These clutches need to be small but with a high clamping force. To work on these design challenges a powertrain Technologies’ 4.5” Power V racing clutch system was selected. The design of a gearbox was also required between the Weber MPE750 and the DU174 in order to maximize the efficiencies of both components. In order to limit the space claim of this gearbox, a single gear reduction method was utilized. Wisconsin’s architecture is without a transmission since the electric drives are able to operate within the full range of vehicle speed at current gear ratios, a transmission was not needed. As a byproduct of not using a transmission, this opened up new space for drivetrain components.

Wisconsin’s vehicle design including is only 224.37 lbs heavier than the stock vehicle. Its center of mass is also a mere 1.11 inches further forward and 0.19 inches further towards the driver’s side than the original stock Saturn Vue. This correlates to 2666.26
lbs (65% total vehicle weight) lying on the front axle while 1433.11 lbs (35% total vehicle weight) sitting on the back axle. This is precisely similar to the stock vehicle, varying only 1% more vehicle weight on the front axle.

**ESS Design and Integration**

For the basis of its electrical storage system (ESS), Wisconsin has chosen to work with Johnson Controls-SAFT (JCS). The original “off-the-shelf” battery pack intended to be donated by Milwaukee-based JCS did not meet VTS requirements for packaging and peak power demand. Through an iterative design process, Wisconsin and JCS have developed a lithium ion battery pack that meets all requirements for safety and functionality. Shown in Table 1 are the high-level specifications for the battery pack.

<table>
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<tr>
<th>Specification</th>
<th>Value</th>
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<tr>
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Because Wisconsin is classified as an EREV team in the EcoCar competition, it was a principle objective to develop a vehicle that could complete an FTP drive cycle on a single charge. Working closely with JCS, Wisconsin was able to select the proper cell chemistry to accomplish a PSAT estimated 21 mile electric-only range.

Another goal of utmost importance was to create a safe ESS packaging design. The new Wisconsin-specified JCS battery pack allows for packaging within the crumple zones. In accordance with safety specifications obtained from JCS, mounting hardware (shown below in Figure 1) for the battery pack has been designed.

The designed mounting hardware also complies with the SAE standard J 2380 in order to minimize the effects of shock and vibration. All mounting “L” brackets are to be welded to the frame rails and then outfitted with soft-mount elastomers.

Additionally, in accordance with EcoCar rules, the battery pack must fit within a specified crush zone. In Figure 2, it is shown that the custom-built JCS battery pack will clear all crush zones.
Structurally, the battery pack utilizes a total of 84 cells rated nominally at 3.6 V each. They are to be packaged into 7 modules, each containing 12 cells. Cells specifications and pack schematics are provided below.

For the EcoCar competition, Wisconsin has designed its first liquid cooling loop to be used for the battery pack. This closed-loop Ethylene glycol cooling system will simplify overall vehicle design, reduce battery pack interior noise, and negate the effects of sand, salt and humidity.

Initially, Wisconsin planned to link the liquid-cooled ESS on a loop along with the MotoTron controllers. However, to ensure sufficient heat rejection in at 115 °F, the highest Arizona temperatures, the ESS has been allocated its own loop. The chosen radiator has a 6 kW heat-rejection rating, and its performance under the US06 drive cycle is shown below in Figure 5.

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<thead>
<tr>
<th>Units</th>
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<td>Energy at C/3</td>
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Summary

The University of Wisconsin Hybrid Vehicle Team has designed a series-parallel hybrid-electric powertrain designed to fit into a stock Saturn Vue for the EcoCar advanced vehicle competition. Per competition year 1 design specifications, the modified Vue must maintain consumer acceptability while simultaneously lowering emissions and providing better fuel economy.

Wisconsin’s design include the use a 150 kW traction motor, a 45 Ah JCS Lithium Ion battery pack, and a “gen-set” composed of a 100 kW motor coupled to a 70 kW turbo charged Weber internal combustion engine. Controls are currently in place that utilize the main traction motor at lower city speeds, only using the gen-set when range extension is necessary. When the vehicle reaches highway speeds, mechanical clutches engage, directly driving the Weber to the road while using the 150 kW traction motor to meet transient load requests. By using the separate power plants in this fashion, Wisconsin will produce power in the most efficient manner under all driving conditions.

All systems went through an extensive modeling process in CAD, PSAT and other mathematical simulation environments. MATLAB and National Instruments, competition sponsors, have donated the required software and hardware necessary for the complete Hardware-in-the-Loop simulation of Wisconsin’s EcoCar competition vehicle.