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Lyn Okse: An Electric Utility Vehicle with Off-Highway Capability

Eric Leonhardt[1], Paul James

[1]*Eric Leonhardt, Vehicle Research Institute,* [2]*Paul James, Department of Anthropology, Western Washington University, 516 High Street, Bellingham, Washington U.S.A,* eric.leonhardt@wwu.edu

Short Abstract

Designed by students and faculty at Western Washington University's Vehicle Research Institute, the Lyn Okse ("Lightning Ox") electric vehicle targets the needs of the campus Facilities Management organization's grounds crews, maintenance and skilled-trades workers. The vehicle combines Neighborhood Electric Vehicle capability with a large cockpit to encourage the replacement of US Department of Transportation Class 1 trucks (Gross Vehicle Weight Rating less than 2679 kg) while reducing carbon dioxide emissions. Vehicle user interface design was developed in collaboration with Facilities staff using student conducted focal follows and ethnography. User experience aimed to identify current use, current vehicle limitations and imagined future use in three contexts; loading, driving and worksite operation. The two passenger vehicle features a cab-forward design to limit wheelbase length to less than 2489 mm while maintaining a minimum 1829 mm cargo bed length and an 8 m curb-to-curb turning circle.

1 Introduction

The Lyn Okse vehicle represents an opportunity for undergraduate students to design, build and test an off-road capable electric vehicle that supports a university campus grounds crew. The vehicle targets the university's goal to improve sustainability by reducing fossil fuel use and carbon dioxide emissions. The university has used two electric vehicles for ten years and has purchased three more electric vehicles to assess how electric vehicles may replace conventional fuel vehicles [1]. The early electric vehicles faced durability challenges, especially in the front suspension [2]. The new electric vehicles have improved range, load capacity and functional storage. However, an electric vehicle with improvements in interior space, storage capacity and greater hill climbing ability will offer a more compelling alternative to conventional fueled vehicles.

The campus initiative for electric vehicles supports broader goals for electric vehicles in the region. Washington State's Governor, Jay Inslee is targeting an increase in electric vehicles used within the state from currently 13,000 to 50,000 by 2020 [3]. Supporting electric vehicles is seen as a way to increase jobs in technology fields, improve air quality, and improve energy independence [4]. BMW currently produces carbon fiber for the BMW I3 electric vehicle and other models at their SGL subsidiary in Moses Lake, Washington [5]. Expansion in the facility has led to more high technology jobs [6]. The state is also concerned with air quality including the health effects from internal combustion engine particulates [7]. Washington is fortunate to produce 69% of its electrical power from renewable hydroelectric sources [8]; the last coal-fired power plant is scheduled to shut down [9]. The state is well positioned to support an increase in electric vehicles.

The paper will document the design process and vehicle requirements gathered, the vehicle specifications, and the final design and construction process. Targets for front impact structure and roof rollover will be covered in addition to the initial tests required to meet those targets. Initial testing of the motor, controller and battery package will also be documented.

2 Vehicle Requirements

Several requirements have been documented through discussions and meetings with potential campus users and project stakeholders. Project stakeholders determined that the grounds crew could most benefit from a purpose built electric vehicle. The student team benchmarked existing campus fleet electric and internal combustion engine vehicles.

Figure1: Existing campus ground crew vehicle

Tools, equipment and supplies utilized on each vehicle were measured, photographed and weighed. The vehicles are used as mobile tool and material storage to carry garden hand tools, a lawn mower, a power trimmer, rakes, shovels and up to two 120 litre containers for wood chips, soil, or compost. The total payload of the vehicle is 226 kg to support 181 kg of tools, equipment and material and up to 45 kg of foul weather clothing, boots and gear for two workers. A 1.83 m bed length is standard for the existing small gasoline powered trucks. Dry, in cab storage for tools, clothing and equipment was desired.

Table1: Dimensions for the existing campus as measured by the team

Vehicle	Canadian Electric Vehicle Might E Truck	e-ride Industries EXV4
Configuration	Electric, 2 passenger, cab forward flatbed	Electric, 4 passenger, rear wheel drive
Door to Door Distance	1219 mm	1371 mm
Floor to Roof	1321 mm	
Seat Rise	254 mm	
Wheelbase	1829 mm	2616 mm
Track Width	1270 mm	1295 mm
Bed Length	1981 mm	
Tire Size	195/65 R 15	215/75 R14
Heater	Electric	Gasoline

A 48 km minimum range was requested to allow the vehicle to benefit from state and federal tax incentives [10]. Existing vehicles can travel 5-11 km a day and use roughly 75 litres per month of gasoline. Tracking energy use from the vehicle is desired so cost and carbon reductions can be quantified. The vehicles serve as mobile offices with a need for all weather protection, heating and defrost. Vehicle maneuverability is valued both on and off-road and the vehicles operate in an environment potentially full of pedestrians. Existing fleet vehicles are modified with campus built tool racks. Additional features such as a tilting bed, snow plow, bed ramp and four wheel drive were discussed as well. The Facilities Management stakeholder team decided to not request a tilting bed on the prototype to reduce some project complexity [11]. The vehicle was originally designed to accommodate both a 95% North American male population and a 5% North American female population. However, the development team features members outside of these targets, including a 2 m tall team member. Numerous design features were discussed with the users and documented including having sufficient vertical adjustment on the shoulder belt anchor points to accommodate the full range of drivers.

Vehicle user interface design was developed through a collaboration between Facilities grounds crew staff and undergraduate anthropology students. Students partnered with a grounds crew member to conduct a 20 minute focal follow, to capture the user interface experience in three different settings. The settings consisted of the loading of tools in the shop, driving the vehicle on and off road to campus worksites, and activities at the worksites. Focal follows were recorded using video to capture the range of current vehicle use. Current vehicle limitations and imagined future use was captured by ethnographic interview during the focal follows. User experience was organized by thematic category and summarized in video presentations shared with the engineering student design team.

3 Design Process

The desired cab space and minimum 1.83 m (1828 mm) flatbed length drove the team to develop a cab forward design, inspired by the 2012 Mighty FC Jeep concept vehicle [12]. Four groups of students worked on the project team. Senior class vehicle design students created detailed designs of the vehicle. Each junior class vehicle student developed a conceptual design for the vehicle. Anthropology students conducted focal follows to gather how users interacted with the existing utility vehicles. Electrical engineering students worked on battery management, motor and controller integration and battery charging integration. The junior and senior vehicle design students worked on the project within their respective vehicle design and senior project courses.

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Vehicle design students followed a process outlined in *H-Point, The Fundamentals of Car Design & Packaging*. The text explains the process as ten steps, including 1) Package and Design Ideation, 2) Set Up Driver's Height and Posture, 3) Set Up Rear Occupants, 4) Select and Install the Powertrain, 5) Set Up Occupants Lateral Location, 6) Create Cargo Space, 7) Size and Position the Driven Wheels, 8) Establish the Wheelbase, 9) Set Up the Front and Rear Tracks, 10) Create the Body and Interior Trim Sections [13]. Students collected inspiration from vehicles with similar missions, including the 2012 Mighty FC Jeep, the VW Vanagon and the Mercedes Benz Unimog.

Anthropology students used focal follow [14] and ethnographic methods [15] to produce video ethnography summaries of how users interacted with existing utility vehicles. Students identified stakeholder volunteers and arranged twenty minute observation periods. These targeted observations were conducted with pre-formulated open ended design questions relating to vehicle use in three contexts, loading, driving and worksite operation. Summary user experience ethnographies identified stakeholder interest in modular and compartmentalized tool and personal item loading and concerns about rear visibility with the current orientation of tools and debris loads. A second iteration of user interface studies looked more closely at the cab as mobile office and issue with visibility and safety while reversing. Cab design features focused on usb and 120v charging capacity, connectivity of personal media devices in place of a stereo and a reverse/backup camera. Users requested secure, accessible and ventilated or heated storage for gloves and jackets at the door, possibly below or behind the seat. Reverse alarms were discussed as tolerated but an annoyance on campus, with the suggestion that they be easily disabled if used.

After gathering requirements and processing conceptual design studies with the students, the author provided students with a computer aided design packaging model that featured a cab forward design with the driver and passenger seated directly over a front wheel. Anthropomorphic manikins of a North American fifth percentile female and a ninety fifth percentile male are located in a potential driving position. The packaging model featured a 35 degree approach angle with 250 mm ground clearance and a 650 mm bed height. A Mazda Miata windshield was selected and included as a potential candidate for the final vehicle. A VW transaxle connected to an electric motor was included. A wheelbase was not fixed, but three wheelbase options were featured in the model to study turning radius: 2236 mm, 2490mm and 2744 mm. A virtual sheet of plywood (1219 mm x 2438 mm) was supplied as a potential bed dimension. Each student was provided the model to help guide their detailed design process and the overall physical dimensions of the vehicle.

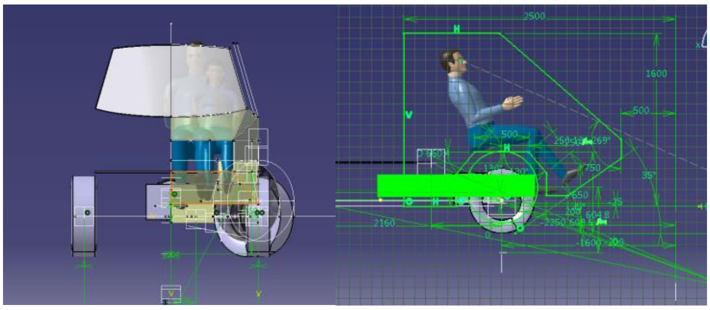

Figure2: Front and side view of initial packaging model

Students built a physical mock-up in plywood and dimensional lumber of the cab seating area. The physical mock-up was used to verify the ergonomics of the seating position, including stepping up into the cab, steering wheel position and pedal assembly position. The student brake design lead created a rapid prototype pedal assembly to validate the pedal position and lower dash location. A representative roof profile was fashioned with lathe and erected above our 2 m tall student. Students introduced the physical mock-up to Facilities Maintenance and Grounds crew members. The team was concerned that the step-up height to enter the vehicle would be too high. Vehicle dimensions for the cockpit were confirmed with the users using the physical model.

Students worked individually and in small teams during the fall 2015 term to design a body including cargo and storage, chassis, front suspension, rear suspension, powertrain including battery pack sizing, interior including heating, and braking. An electrical engineering team focused on integrating the high voltage electrical system with the battery management systems and charging system.

A conceptual vehicle computer aided design was created at the end of fall 2015, pictured in figure 2 below:

Figure3: Lyn Okse Concept Design Fall 2015 (Alec Darr)

During winter 2015, students repackaged the original design, while refining the designs for the front and rear suspension and powertrain. The new package added width to the cab for more shoulder room and added height for taller drivers. The added width and height resulted in challenges to the A-pillar size. Borrowing a concept from a Volvo show car, the A-pillar is ventilated with a triangular space frame. A study of visibility and sight lines was undertaken to ensure that the visibility would be sufficient for both 5% female drivers and 95% male drivers. An upward visibility angle of greater than 7 degrees for 95% male drivers and greater than 4 degrees downward visibility for 5% female drivers was achieved. A view of this study is pictured in figure 4 below:

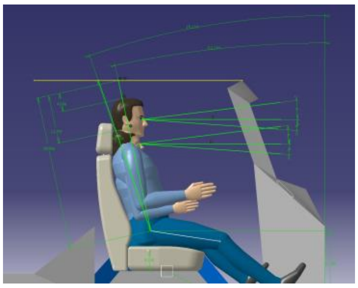

Figure4: Upward and downward visibility study

Students built a physical model of the side below-bed storage to allow the users to determine how the storage should open and to validate the 1 meter long size of the box. A 125 mm reduction in behind the seat cab storage, combined with a detailed rear suspension design resulted in significant reduction in wheelbase to 2195 mm from the 2490 mm proposed in the fall 2015 design. The new design is pictured in Figure 5 below:

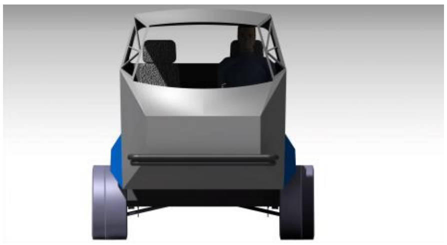

Figure5: Lyn Okse design with ventilated A-pillar

4 Vehicle Design

4.1 Body and Chassis Construction

The cab forward, two passenger flatbed design features an aluminum monocoque structure bonded and fastened from aluminum honeycomb panels. The aluminum honeycomb panels are 12mm thick by 508 mm wide by 2438 mm long. The panels were chosen for the prototype because they were surplus, stiff and 7.78 kg per panel. The bed is formed by three of these panels spliced together to form 1500 mm wide bed. Each panel has at least one 0.76 mm skin machined away for at least a 50 mm wide strip along the entire length while the core is machined back at least 25 mm. The center panel has both its skin on one side and core machined back on both long edges to enable all three panels to be spliced together. The panels are joined with a thickened epoxy. Two panels, 508 mm apart, are set perpendicular to and below the bed to form a backbone spine. L shaped brackets bolted and bonded to the flatbed strengthen and capture the twin vertically oriented panels. The bottom of the chassis is covered with another panel to form a closed central box that runs continuously from the rear of the chassis to the rear of the front wheel wells. This bottom panel is bolted to the vertical panels to facilitate removal and service of the driveline.

Two 1 m long storage boxes are structurally bonded and fastened below the bed. The internal storage is 458 mm high by 446 mm deep. The forward plane of the storage box forms the rear surface of the cab. The cab sits on top of the bed/lower chassis structure and is structurally bonded and fastened to the bed. A cut and fold technique is used to shape and form the bends in the aluminum honeycomb panels to form the structural wheel arches at the bottom of the cab and the front of the cab. As an example, each wheel arch features a 370 mm wide panel with a strip of facing removed on the inside of the joint so that the 12 mm honeycomb core can be cut to a depth of 6 mm. The panel is then bent to a 130 degree angle and filled with a thickened epoxy potted into the cut area of the joint.

Figure6: Three quarter rear view with side box storage and fenders

The team is attempting to meet Federal Motor Vehicle side impact, front impact and roof structural requirements. Although the vehicle is targeting low and medium speed electric vehicle requirements, with a 56 km/h maximum speed, the practice of meeting the targets is a good technical challenge for students and provides for discussions about vehicle safety and ethical engineering practices. The target speed for a front impact test is 56 km/h. The team is targeting a force based on a 196 m/s^2 (20 G) acceleration upon impact. The expected test weight including a required 136 kg cargo load during the test is 880 kg. The front impact force design target 172 kN. To manage this force, the front of the vehicle is supported by an inverted u-shaped center console that is 479 mm high and 150 mm wide constructed from cut and folded aluminum honeycomb panel. The spine travels from the front of the cab to the rear of the cab 1870 mm. The spine is supported by the structural, honeycomb cab interior floor that is 566 mm above the ground. A second horizontal panel supports the bottom front edge of the cab at a height of 406 mm from the ground. These two horizontal panels straddle the upper and lower bounds for front bumper height in the U.S. Federal Motor Vehicle Safety Standards. Initial crush testing of test panels indicate that the bare unsupported panels cannot meet the required impact loads along their edges. The physical testing of the bare panels is within 10% of engineering calculations for honeycomb panels. However, when the panels are constrained along the edges with u-sectioned extrusions to prevent peel and the panels are bent using the cut and fold technique for the interior console, than the physical test loads show that the aluminum skins can carry 138 MPa over the cross sectional area of the panel edges (panel facing edge). Additional physical testing of a front structure will be carried out on a 68 metric ton press. A drop tower test may be performed on some panels as well.

The U.S. Federal Motor Vehicle Standard 216 governs roof structure and was amended in 2009[16]. The new rule requires vehicles with gross vehicle weights of less than an equivalent mass of 2722 kg must support a load on the front edge of the roof to A-pillar transition of 26.7 kN or three times the unloaded vehicle weight. For the Lyn Okse vehicle the unloaded vehicle mass is target gross vehicle weight is 650 kg so the target force requirement is around 6.5 kN. A four passenger vehicle designed and tested at the Vehicle Research Institute, Viking 32, had an A-pillar designed by the author to support a 57 kN load [17]. The off-road use of the vehicle indicates that rolling over while traversing a hilly section of campus will be possible.

4.2 Suspension Design

Due to the potential for off-road travel with this vehicle, the suspension was designed to match the loading conditions of an SAE Baja vehicle designed by the student team. A vertical acceleration of 7 G or 67 m/s^2 was chosen to determine the target loading for the suspension and chassis. An overall suspension travel target of 305 mm with 178 mm in drop and 127 mm in bump was set as a design goal. Depending upon the load of the chassis, and the spring rate of the tire, this effectively sets the unsprung mass wheel rate and frequency. The independent front suspension features a double wishbone design with a 430 mm long upper control arm and a 450 mm long lower control arm. A first generation Mazda Miata MX-5 cast iron upright provides for the purchase of readily available wheel bearings, ball joints, and replacement uprights. A conventional coil over spring and damper assembly is specified. Kinematic analysis was performed to reduce bump steer through the placement of the front steering rack and to manage camber change in roll. Initially the steering angle for the upright was targeted at 55 degrees to achieve an 8 m curb-to-curb turning circle. The 55 degree target was not able to be met due to joint limits and physical constraints of the suspension members. However, a 50 degree turn angle is achievable and still meets the 8 m curb-to-curb turning circle with the 2195 mm wheelbase. A rack and pinion assembly from a first generation Honda Insight features inboard mounts for the inner steering toe links. The long toe links allow greater freedom to adjust the toe link and manage the resulting bump steer. Several vehicles now feature this style of rack and pinion; the Honda part happened to be donated and available. Conventional racks from a Volvo and various Toyota models were also tested for suitability.

The rear suspension features a modified VW bus semi-trailing arm design. The 412 mm arm length is roughly 75 mm longer than the stock design and nearly achieves the full 305 mm desired travel. The design was chosen to provide an independent suspension with some camber gain in roll while allowing the use of a rear mounted transaxle. The parts are designed for off road modified and race vehicles using VW transaxles. A significant off-road VW suspension aftermarket exists to provide significantly lower costs than custom fabricated costs and the parts can be replaced easily should they be damaged in use.

One challenge with the suspension design is that the front spindle supports a 4 by 100 mm bolt pattern for wheels while the rear suspension is a 5 by 130 mm bolt pattern. A spacer is used on the front wheels to convert the front axle to the 5 by 130 mm bolt pattern. This will simplify spare wheel selection and tire rotation. Yokohama G Lander tires in a 205 70 R15 size are selected for their DOT approved, highway use rating, off-road capability, and light weight at 11.3 kg per tire.

4.3 Powertrain

The latest electric vehicles purchased for campus use, the Mighty E truck and EVX4, perform much better than the 10 year old GEM electric vehicles. The new vehicles benefit from more powerful motors and the improved, lithium-ion battery technology. The challenge for even the new vehicles is that the campus environment is nestled on top of a steep hill. For a loaded electric vehicle this forces the users to use alternative routes or to select gasoline powered vehicles to move various loads. Using Google Earth, students were able to graph hill inclines around campus. An angle of 18 degrees was measured on one high traffic route. A simple, linear math model for vehicle efficiency based on anticipated aerodynamic drag, rolling resistance, drivetrain losses and vehicle weight was used to look at power requirements, battery pack size, and vehicle range. Rather than watt hours per mile, the efficiency data was converted to relate the data to an efficiency measure with which campus users are familiar, miles per gasoline gallon equivalent or MPGe. Table 2 below shows the power and efficiency estimates at two loading conditions, lightly loaded and a projected gross vehicle weight rating traveling up an 18 degree slope:

Table2: Power and efficiency climbing an 18 degree slope

Load, kg	Speed, kph	Gear	Power, kW	Efficiency, MPGe
817	22	1	20	24
817	32	2	29	23
817	48	3	44	23
1225	22	1	30	16
1225	32	2	43	16
1225	48	3	65	15

The chart indicates why the existing vehicles are likely to struggle with the hills on campus. The unladen power requirement is near the maximum power of the existing campus electric utility vehicles. The existing vehicles feature direct drive with a single gear reduction. This is superior for cost, weight and the user interface because there is no shift gears. However, for a vehicle carrying a load, even the superior torque of an electric motor is not sufficient for hilly terrain.

As a result, the team selected a VW 091 bus transaxle as a low cost, lightweight means of providing multiple gear ratios. The magnesium case weighs 23 kg with a complete transaxle around 30 kg. Strong aftermarket support provides options for upgraded gears and high quality, limited slip differentials. Ideally the powertrain would feature four wheel drive to provide traction and limit damage to sensitive environmental landscapes. A limited budget prevents this option. The limited slip option helps improve traction and reduces the chance to damage landscaping. The VW 091 transaxle provides four forward gears and reverse with a wide range of final drive ratios available.

The transaxle can be coupled with two electric motor options, an Enstroj Emrax motor and a Perm water cooled motor. The Perm water cooled motor produces 32 kW peak and 23 kW continuous and can be connected to a Sevcon Gen4 Size 6 controller with a nominal 96V output, peak charging voltage of 116V-120V, and 550-650 A depending upon the specific model. This controller can be purchased for close to $1,000 USD. U.S. pricing for both European motors varies with exchange rates, but the Perm combination with a Sevcon Gen4 Size 6 controller can be purchased retail for prototyping for around $5,000 USD. The Perm option is reliable with water cooling and reasonably priced, but the MOSFET design of the Gen4 Size 6 limits peak voltage. The cast aluminum case for the motor is roughly 11 kg and nearly half of the total motor weight.

A higher cost option is the Enstroj Emrax option with a Sevcon Gen4 Size 8 or 10 controller. The Enstroj motor is roughly the same cost as the Perm motor for prototyping but the author anticipates volume pricing to be significantly less for the Perm motor. The Sevcon Gen 4 Size 8 or 10 controllers are several times the cost of the Size 6 controller, so this combination may not be suitable for a volume producer of electric utility vehicles. However, the weight and power output of the Enstroj demonstrates future vehicle capability. This motor is capable of 75 kW at 3000 rpm with 300 V controller input voltage and up to 150 kW at 6000 rpm with 600 V. The motor is 11 kg. The entire housing of the motor rotates—it is designed for powered sailplane use—so an external guard may be required for some applications. This motor is being tested for installation in the vehicle. A thrust analysis was conducted with the Enstroj option to determine the potential for maximum vehicle acceleration and hill climbing ability. The results are available in table 3 below. It is clear that the unladen vehicle will be traction limited in both first and second gears. Software controls and a load level sensor may be used at a later date to limit power. Speed will need to be limited as well, although the team may simply lock out fourth gear.

Table3: Emrax motor and 091 transaxle torque and thrust availability

Gear	Gear Ratio	Gear Ratio Overall	Vehicle Speed, kph	Peak Motor Torque (240 Nm) at Axle, Nm	Peak Tractive Thrust at Rear Wheel, kN	Continuous Motor Torque (92 Nm) at Axle, Nm	Continuous Tractive Thrust at Rear Wheel, kN
1	3.78	17.27	22	4146	14.7	2155	7.6
2	2.06	9.41	40	2259	8.0	1174	4.2
3	1.45	6.63	56	1590	5.6	827	2.9
4	0.85	3.88	96	932	3.3	485	1.7
Reverse	3.67	16.77	22	4025	14.3	2092	7.4
Final Drive	4.57						

4.4 Efficiency and Battery Pack Sizing

A vehicle energy study was performed to determine the potential vehicle range and to guide battery pack sizing. The study looked at an unladen vehicle mass of 817 kg and a maximum loaded mass of of 1225 kg. The study considered a frontal area of 2.514 m^2 with coefficient of drag of 0.55 and a tire rolling resistance of 0.015. A driveline efficiency of 85.5% is estimated. Power is motor power required and does not consider battery loss or charging efficiency.

Table4: Efficiency and energy required for level road travel

Speed, kph	Vehicle Mass, kg	Power, kW	Efficiency, Wh/km	Energy in kWh for 16 km range	Energy in kWh for 32 km range	Energy in kWh for 48 km range	Energy in kWh for 80 km range
22	817	1.1	49.7	0.8	1.6	2.4	4.0
40	817	2.9	73.1	1.2	2.4	3.5	5.9

48	817	4.3	88.2	1.4	2.8	4.3	7.1
22	1225	1.6	69.2	1.1	2.2	3.3	5.6
40	1225	3.7	92.6	1.5	3.0	4.5	7.5
48	1225	5.2	107.7	1.7	3.50	5.2	8.7

Originally an existing 4.4 kWh pack was considered. However, this pack would not make the range requirement at higher speeds or loads. Next a series of battery cells were considered including Calb 100 Ah cells, Melasta cells, cells for radio controlled vehicles and the Panasonic 18650 cells. The battery lead began looking at a 7.4 kWh pack size as a reasonable trade-off between cost, weight, space and performance. Individual cells were compared for cost, performance, specific power density, specific energy density, and specific volume density. The 18650 laptop cells were the most reasonable cost, but would have required 720 cells and required a significant cost upgrade to an existing battery management system so the cost benefit was reduced. The max continuous C rating was listed at 2C which limited pack power to 18 kW even with a 9.1 kWh pack. Finally a Melasta SLPB8070170 cell was chosen with a 10 Ah and 10 C rating. The resulting pack of 200 cells could produce 74 kW of power; a better fit for the motor capability. The charging rate was much higher at 3C to allow rapid pack charging. With further testing of the vehicle, the power requirement may be able to be reduced, then a lower cost pack of 18650 cells would be more economical.

Table5: Melasta SLPB8070170 Specifications

Cell Height	170.5 mm
Width	69.5 mm
Thickness	7.4 mm
Mass	305g
Nominal Voltage	3.7V
Rated Amp-Hours, 1C	10 Ah
Max Charge Rate	3C
Max Discharge	10C

The pack is laid out with two cells in parallel and then 100 cell pairs in series to produce a nominal pack voltage of 370 V. The total pack height is 170.5 mm by 278.0 mm wide and 370.0 mm long. The pack is centrally located within the center spine at the back of the cab. A space of 508 mm by 390 mm is reserved for the 61 kg pack. Additional space exists below the bed and behind the cab for a longer range version. Cell costs will limit the commercial viability of that option for this market.

5 Cost Analysis

A detailed bill-of-materials for the project was generated by the team by functional category such as suspension, battery, powertrain, chassis, etc. The detailed BOM included initial estimates for cost based on projected component costs. For example, at the beginning the Geolander tires were not selected but a similar B.F. Goodrich tire was selected for cost analysis. Potential components for the suspension, drivetrain including the gearbox, battery pack cells, electric motor, battery management system, etc. were listed in the BOM with projected costs based on talking with vendors or internet pricing data. This process started in February of 2014 with a completed draft BOM submitted for funding in September of 2015. The detailed design process refined this cost analysis through December of 2015. Students compared and contrasted various details such as lighting, batteries and suspension components and selected components based on the teams' values and evaluation of trade-offs for cost, performance or styling. For the battery pack in particular, a detailed analysis of each cell and potential battery pack configuration occurred. For other systems, such as the brake system, the author reviewed the brake lead's analysis and attempted to reduce the costs by offering alternative components. The final prototype budget is listed below.

Chassis	$6,263.00
Powertrain	$19,778.95
Suspension Components	$6,139.49
Body (including lighting)	$2,881.00
Interior and Cargo (including heating)	$1,634.00
Occupants (Seating and user interface)	$1,428.00
Outreach Funds (public and campus awareness)	$500.00
Total	$44,418.58

6 Specifications

The two passenger vehicle places the cockpit above the front impact and bumper zones and provides a flatbed height of 750 mm that is free from rear wheel or fender geometry. The initial pack stores a nominal 7.4 kWh.

Table6: Vehicle Specifications

	Value	Units		Interior	Value	Units
Curb Weight	650	kg		Seating Capacity	2	
Test Weight	750	kg		Headroom	976	mm
GVWR	1225	kg		Leg Room	978	mm
				Shoulder Room	1300	mm
Wheelbase	2195	mm		Seat Width	2x530	mm
Track	1400	mm				
Length				Bed Length	1828	mm
Width	1624	mm		Width	1400	mm
Height	1968	mm		Height	750	mm
Powertrain				Battery Pack		
Brushless DC	56@3000rpm	kW		LiPo Cells	3.7	V per cell
Max Torque	200	Nm			10	Ah per cell
Gearbox, Final Drive	4.57	Ratio		Max Current, C	10	C
1st	3.78	Ratio		Pack Energy@1C	7.4	kWh
2nd	2.06	Ratio		Pack Arrangement	2x 100	Parallel x Series
3rd	1.45	Ratio		Nominal Voltage	370	V
4th	0.85	Ratio		Peak Current	200	Ah@10C

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Authors

Eric Leonhardt attended Whitman College (BA Economics), Western Washington University (BS, Industrial Technology Vehicle Design), and the University of Michigan (MS, Automotive Systems Engineering). He worked for EDS serving General Motors in lean manufacturing and virtual manufacturing. At DaimlerChrysler he developed computer aided tools for engine and transmission manufacturing. He presently teaches vehicle design at Western Washington University while creating alternative fuel systems and composite hybrid electric vehicles with undergraduate students.

Paul James is a Senior Instructor in the Department of Anthropology at Western Washington University. By training he is an applied medical anthropologist specializing in evolutionary medicine and evaluation of community based health interventions. He has conducted fieldwork in Bolivia, Paraguay, Mexico, and the western US. Paul's research and teaching focus on a broad array of directed cultural change in response to health, social and ecological problems. Paul attended Western Washington University (M.A. Anthropology) and the University of New Mexico (M.S., ABD Human Evolutionary Ecology).