AC 2010-29: AN ALTERNATIVE RIDE - UNDERGRADUATE STUDENTS AND FACULTY AT WESTERN WASHINGTON UNIVERSITY DESIGN A HYBRID ELECTRIC BUS

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An Alternative Ride - Undergraduate Students and Faculty at Western Washington University Design a Hybrid Electric Bus

Abstract

Students and faculty at Western Washington University's (WWU) Vehicle Research Institute (VRI) are designing a hybrid electric bus for public transit operators in Washington State, with potential national appeal. The initial focus of the bus design is to serve communities that offer on-demand, or access transit service, which provides transportation to residents with limited mobility options. By using a modular design approach, the team has chosen to allow for a range of potential vehicle applications, including school bus, shuttle bus, and commuter service variants. An all-electric version is also planned for shorter distance route coverage. Considering the design goals of increased fuel economy, as well as improved maintainability and serviceability over existing products, the resultant reduction in overall operating costs will provide added incentive for fleet operators when considering new vehicle purchases. Improvements in vehicle aerodynamics, use of lightweight construction materials, and a hybrid powertrain will help contribute to greater fuel economy. Unique design and fabrication techniques for high performance structural composites will be utilized to reduce curb weight by 30-50%, when compared to conventional steel chassis design benchmarks. Self-imposed mandates adopted by the WWU R&D team include design and manufacturing sustainability focus, which are reflected in all architectural, materials selection, and manufacturing process decisions. An additional design goal targets the ability to use a range of alternative fuels by using a modular hybrid powertrain and open source control strategies that enable utilization of regional feedstocks available to the purchaser.

The hybrid bus project combines undergraduate Vehicle Design students with Engineering Technology (ET) faculty and local industry representatives to form the primary R&D team. Students majoring in the Industrial Design and CAD / CAM programs at WWU have also played a major role in helping to develop interior, exterior and chassis design concepts. The R&D team met with a cross section of transit authority members from across Washington State in order to capture the needs of a variety of stakeholders involved in public transportation. Through the efforts of a multidisciplinary team that is utilizing automotive industry best practices such as Quality Function Deployment (QFD) and Design Failure Mode Effects and Analysis (DFMEA), a paradigm-shifting vehicle is being developed for intended production implementation by 2015. The team is in the process of developing computer-aided models of the bus body and chassis, and is finalizing mathematical models of bus performance, which will assist in powertrain selection and battery pack sizing. A preliminary prototype bus design should be complete by the summer of 2010.

This paper will focus on the details of sustainable design decisions that are being used by the collaborative team for the vehicle. The reader will understand the major concerns indicated by the transit industry that are driving the need for change in specific areas, as well as the solutions the team is developing to address these concerns, while striving to enhance the ride experience for all.

A second paper has been drafted and submitted for ASEE consideration which covers the educational aspects of this project and is entitled "Western Washington University's Hybrid Bus – A Multidisciplinary Approach to Project Based Education". Readers interested in the pedagogical discussions associated with this project are encouraged to reference this document.

Background

Preliminary research during the summer of 2007 focused on a Type C school bus (front engine / cowl chassis), with a desire to assist public education by providing a vehicle that would allow them to redirect their funding from increasing fuel and operational costs, to their primary mission of educating children. Concurrently, Kitsap Transit's Executive Director, Mr. Richard Hayes, visited Western Washington University's Vehicle Research Institute with a proactive vision to address rising fuel costs. Kitsap Transit, a regional transportation authority located in Bremerton, WA, is the most fuel efficient agency in the region with a 33 L/100 km (7.2 mpg) fleet average; however, they are concerned with the operational impact of predicted $5-$7 per gallon fuel costs by 2012. With an average fuel economy level of 26 L/100 km (9 mpg) for their current 8 m (26 ft) paratransit shuttle buses, Kitsap Transit has provided a benchmark for the WWU R&D team to improve upon for their similar sized project vehicle. Kitsap Transit represents a fleet customer with like-minded goals, continues to solicit involvement from other regional transit groups, and brings with them additional avenues for potential project funding that public school systems do not possess. The initial focus may still be met by addressing the needs of public transit operators first, and by maintaining a modular design approach, a reconfigured interior will allow usage by public school systems.

In February of 2008, Kitsap Transit and WWU teamed up to provide a forum for establishing the general scope of the project in order to provide a vehicle that would suit the needs of a range of potential customers in the region. Common design targets established by the participants focused on a low floor, (15-17) passenger paratransit vehicle with room for two wheel chair stations, in a package less than twenty-five feet long. The term "paratransit" is defined by Merriam-Webster as "transportation service that supplements larger public transit systems by providing individualized rides without fixed routes or timetables"[1].

This paper will briefly outline the VRI's history, challenges facing public transportation, requirements for the new bus design, design progress, performance modeling of the bus, and extension of the classroom for this practical design application.

Vehicle Research Institute History

Western Washington University's Vehicle Research Institute was officially established in 1975 by Dr. Michael Seal, Professor Emeritus. His initial vision of providing society and the students of WWU with concept vehicles that pushed the boundaries of conventional designs continues into the 21st century. Since Viking I, named for the school mascot, more than forty-six vehicles have been built by students and faculty. The primary themes of reduced weight, optimized aerodynamics, and alternatively fueled designs can be seen in the majority of the Viking vehicles produced to date, excluding the purpose built SAE Collegiate Design

Competition Baja and Formula vehicles. The latest example, Viking 40, is a two-passenger sport coupe whose chassis and body are constructed of carbon fiber composite materials, with a curb weight of 544kg (1200 lb) and fuel economy goal of 4.3 l/100km (55 mpg). Equipped with a 1.6L Honda VTEC engine, it will serve as a chassis prototype for Viking 45, the next passenger car project targeted to compete in the Progressive Insurance Automotive X-Prize Competition, whose goal is to challenge vehicle designers to create production-feasible vehicles with 100mpg (2.4 l/100km) average fuel consumption levels. This vehicle will utilize an optimized hybrid powertrain from a 2007 Honda Insight. Fabrication of Viking 45 started over the summer of 2008, and is targeted for completion in the spring of 2010.

Over the years, the Viking cars have proven to be a means for applying concepts obtained in the classroom to practical incarnations of student and faculty innovations. Past projects include the solar electric Viking XX vehicle that placed 2nd in the 1990 GM Sunrayce and 5th in the 1990 World Solar Challenge in Australia, and Viking 29, a thermalphotovoltaic concept vehicle that allowed partnering with the United States Department of Energy and Department of Defense. The WWU VRI has developed a reputation for pushing the limits with powertrain designs, superior aerodynamic shapes and materials applications. In 2002, Viking 32 was designed as a parallel hybrid vehicle that contains a 75 kW (100 hp) UQM electric motor driving the front axle, and a 1.7 L Honda spark ignition engine driving the rear, converted to run on biomethane produced from cow manure. It achieves an average gasoline equivalent mileage rating of 4.5 l/100km (52 mpg), while running on refined methane from dairy cows. Initiated in 2004, under the direction of Professor Eric Leonhardt, the VRI has developed a biomethane refinery in cooperation with the VanderHaak dairy farm in Lynden, Washington, and continues to develop the commercialization aspects of this initiative. These examples illustrate that the WWU VRI has established itself as an institution with the capability to design, fabricate and implement alternative vehicle options for the future.

Viking 32 – Biomethane / Electric Hybrid Vehicle

Public Transit Challenges

Increasing fuel prices continue to outpace the rate of more fuel efficient vehicle designs entering into the market. Existing bus manufacturers have not strayed far from the path of convention with their ongoing product offerings. Low fuel costs in the past meant that factors such as durability and initial vehicle cost outweighed fuel efficiency as a critical design element. The authors believe that the current paradigm of sheet metal bodies on steel ladder frame truck chassis cannot meet the changing needs of the public transit market. A new type of vehicle is required.

Typical Type D (flat front, transit style) buses are in the 9-10.7 m (30-35 ft) length range, with capacity for 19-30 passengers. Conventional architectures such as the Ultra Low Floor models from Bluebird Corporation weigh in at a hefty 11800 – 13100 kg (26,000 - 29,000 lb) GVW[2] range, and are manufactured on steel ladder frame rolling chassis structures, with the coach compartment added on at a later time. Conventional materials include stamped steel or aluminum body panels, tempered glass windows, and foam-stuffed seating. These high density materials combine to produce the heavy weight vehicles that continue to travel the roadways today. Based on continuous improvement initiatives for reducing new product time to market, a constant effort toward material and process cost reductions, and the current segmented manufacturing assembly structure (rolling chassis and body produced in separate locations), fleet operators indicate that it is difficult for original equipment manufacturers (OEM's) and tier one suppliers to provide innovations with advanced materials and non-conventional designs, while maintaining competitive product costs for their customers.

Type C Chassis

Type D Chassis

Combine the high density material selections with non-aerodynamic structures, and throw in the global direction of crude oil and refined fuel prices, and the results are daunting for public transportation operators attempting to develop long range budget plans. Based on estimates of known oil reserves, according to J. Howard Kunstler, in his 2005 book, *The Long Emergency*, "The world [was then] using 27 billion barrels of oil a year. If every last drop of the remaining 1 trillion barrels could be extracted at current cost ratios and current rates of production, which is extremely unlikely, the entire endowment would last only another thirty-seven years."[3] Even with the possible discovery of untapped oil reserves, consumption levels by current industrialized nations and the continued industrialization of nations such as China, with its population of more than 1.3 billion people[4], and India at 1.1billion, compared to the US population of nearly 304 million[5], combine to strain an already overstretched global resource.

Additional concerns indicated by transit providers include the need to diversify routes for customers that are unable to provide their own transportation, yet are not able to utilize existing transit methods or standardized schedules. When transporting disabled passengers, the common concern for passenger and driver safety has been indicated by many fleet operators having to deal with lift mechanisms used on non-low floor vehicles. The combination of these factors further stresses the need for groups such as WWU's VRI to work with manufacturers and customers in an effort to develop more fuel efficient, sustainable and utilitarian vehicles.

Initial Design Requirements

Cues from previous VRI vehicles, ongoing research efforts, and input from transit fleet operators provide the basis for continued concept refinement. Participants from more than twenty transit agencies and transit bus retailers from across Washington State met on the WWU campus in February, 2008 to develop a project plan and requirements for the bus concept vehicle. The group agreed to focus the design on a paratransit bus with capacity for fourteen passengers, including two wheelchairs, in addition to the driver. The intent is to offer a vehicle that may be driven without a commercial driver's license (CDL) in Washington State, a factor appealing to some transit authorities and taxi service operators. In Washington State, operators are required to possess a CDL if any of the following apply: the GVW is greater than 11790 kg (26,000 lb), the vehicle is designed to transport more than (15) people, it is a school bus, or hazardous materials are being transported.[6] These mandates are common for the majority of the continental US. The additional capacity of up to seventeen ambulatory, or fifteen plus two wheelchair passengers, was indicated by several transit operators in attendance. The R&D team has determined that the underlying goal of design modularity should accommodate this request by providing sufficient floor space and power to meet this demand. Cargo capacity, including passengers, is limited to 1360 kg (3000 lb) to match the capability of existing paratransit vehicles of similar size. A low floor design was required to eliminate steps from the vehicle, which will aid in reduced likelihood of passenger accidents and associated costs, as well as provide faster ingress and egress. This assists in providing shorter transit stops, and a reduction in overall travel time, which can lead to a reduced overall fleet size. Also, by incorporating a ramp, elimination of wheel chair lifts can reduce injury to drivers and wheelchair occupants, while reducing cost and weight. The following condensed list provides highlights of the desired characteristics derived from the regional workshop:

- Estimated 6.7-7.6 m (22-25 ft) overall length with a 4 m (13 ft) wheelbase based on passenger configuration
- Maximum width 2.45 m (8 ft)
- Goal of 7.62 m (25 ft) maximum turning radius
- Minimum range of 322 km (200 mi) - special events required up to 290 km (180 mi) with existing buses
- 113 km/hr (70 mph)maximum speed
- Ideally, all electric power, subject to cost and weight constraints
- Altoona, PA Tested (Federal Transit Authority certification to allow funding assistance)
- Meets or exceeds Federal Motor Vehicle Safety Standards
- Bridge laws considered for 4 MPa (580 psi) tire load limits
- Passenger comfort managed for bus temperature and solar loading; air conditioning requirements
- Integration with "Smart Bus" Technology / Information Systems
- Fire suppression and flammability requirements

During research activity, the authors discovered another group with similar goals in mind for acquiring a fuel efficient shuttle bus. The Hybrid Truck User's Forum (HTUF), a consortium of national bus fleet operators established by WestStart/CALSTART, has developed a list of design goals for their vehicle. The WWU R&D Team has determined that the ideal design solution should meet or exceed the requirements established by both groups, in order to provide a vehicle with appeal to a larger consumer base. A detailed design goal specification sheet and proposed features list are attached in Appendices A and B, which target the extremes of both representative groups, as well as R&D team proposed elements.

Design Approach

The remainder of this document will highlight the current hybrid bus project design direction for major system or sub-system areas. It will also discuss critical factors being considered for areas that present ongoing challenges based on available technologies, and those on the verge of next generation technology offerings.

Due to the broad nature of the Hybrid Bus project and the many aspects of the vehicle that the team seeks to optimize, the project continues to fuel a significant number of independent study and senior project activities that enable the students to explore individual areas of interest, while providing valuable input to the team. The R&D Team is organized similarly to automotive industry design groups, and has established informal sub-groups that are tasked with activities pertaining to their specific areas. Additionally, an experimental design course is planned for the summer of 2010 that will expand on the current team organization and emulate an industry setting by establishing functional sub-groups with reporting supervisors and established work goals. Formal cross-functional design review sessions and manufacturing process planning will be included.

The overall design methodology embraced by the WWU VRI team continues to focus on a multi-faceted customer approach. Our goals seek to satisfy passenger, driver and service technician needs, in addition to those expressed by the fleet operators. By including improvements in areas such as passenger and driver safety and ergonomics, disabled passenger access, fleet durability, design modularity and serviceability, the overall product design will provide a robust solution for all stakeholders involved. The intent is to offer design features that will increase ridership by enticing current non-public transportation users into riding the bus based on their ability to multitask with such amenities as on-board internet connectivity, video options and battery operated equipment recharging.

Improved ride comfort, in the form of ergonomically enhanced seating and storage options, as well as improvements in disabled passenger access and more efficient wheelchair restraint systems are planned, which will allow for faster ingress and egress of all passenger types. Improvements in driver visibility, access and vehicle operations will enhance effectiveness when driving and dealing with all passengers. A modular design approach for major sub-systems, as well as design for manufacturability, maintenance and serviceability, will positively impact fleet operators and their overall bottom line.

As previously mentioned, the Hybrid Bus R&D Team is composed primarily of undergraduate students in the Engineering Technology Department at WWU. By weaving threads of the design project into select classroom activities and enlisting the assistance of a broad range of students, a cross-functional team approach has been implemented. Several classes of Industrial Design majors were approached for assistance with conceptual renderings of exterior and interior features, based on initial input from the design team. Their response has provided much food for thought in areas such as exterior shape, modular seating systems, optional standing passenger handrails, driver ergonomics and bicycle storage systems. A sample of their renderings is included in Figure 1. Engineering students involved in Industrial Quality Assurance classes have assisted with QFD studies which focus on a "voice of the customer" approach, and place prioritization on specific design solutions based on their interrelated affect and overall impact on the product. Several studies have been initiated in the areas of interior, exterior and powertrain design. A sample of one of the "work in progress" QFD studies is shown in Figure 2 for the hybrid bus interior. Note that the technical importance ratings indicate prioritization of an optimized wheel chair ramp (rated 177), centrally located driver (147), and ADA compliant aisles and access (rated 139). The technical importance rating represents the sum of all individual item products of customer requirement priority rating multiplied by the relationship matrix rating. In other words, the technical importance rating is based on customer requirement priority and strength of the related technical solution, and its potential to address multiple customer concerns. An additional analytical tool being used by the team that was adopted from the automotive industry includes design failure mode effects and analysis (DFMEA), which is a tool that allows for group analysis of critical design aspects, and prioritization of preventative actions for enhanced designs.

A Vehicle Design class has provided concepts for exterior shape based on hand-crafted 1/10 to 1/16 scale models tested in the WWU wind tunnel and quantified for aerodynamic drag coefficients. In all aspects, the students were excited to be a part of what is turning out to be a "departmental" design initiative. By including aspects of the project in multi-disciplinary studies, productivity increases for the core "volunteer" R&D team, the collective thought process improves design robustness due to a diverse approach, and project goals are continuously scrutinized and refined.

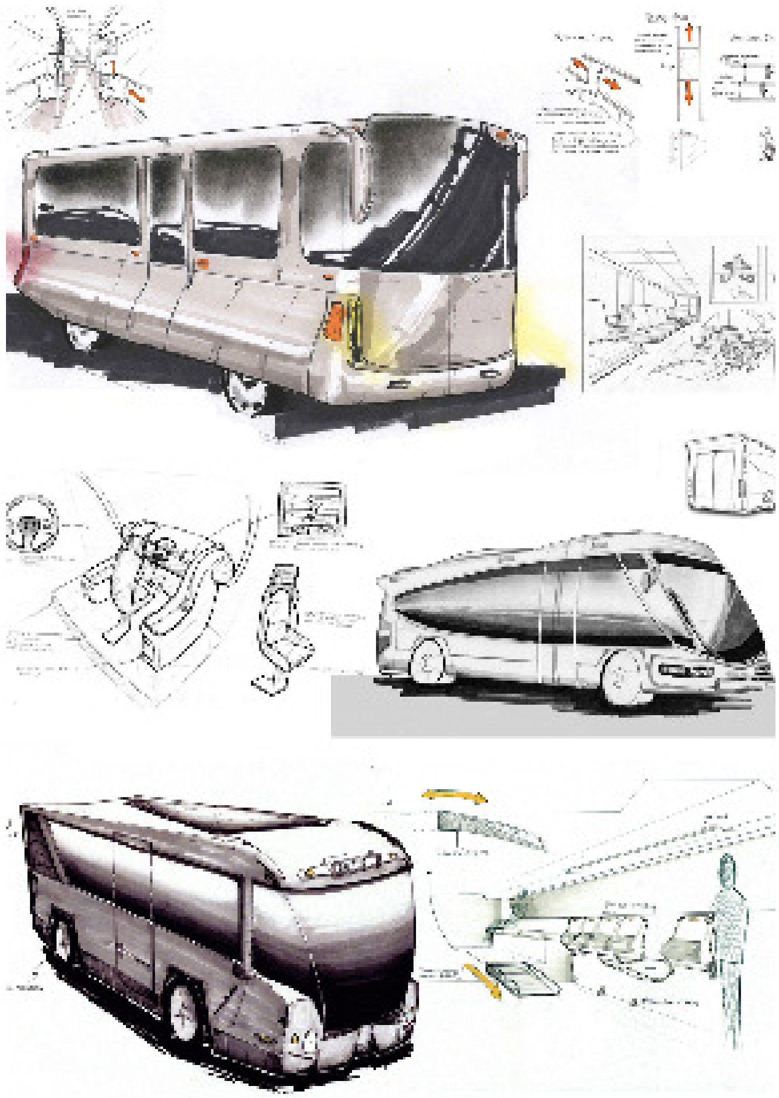


Figure 1 – Example of Industrial Design Students Conceptual Renderings

The QFD matrix in Figure 2 is incomplete, but the prioritized customer requirements can be obtained from this analysis. To increase robustness of the customer priority rating values, a reference chart is included which reflects actual ratings of the HTUF[7] group, as indicated in their request for proposal for a similar type vehicle. The design approach continues to focus on group analyses in many critical areas, but also relies on the results of independent study activities, which allow the students more in-depth research opportunities in the areas of their choosing. Prioritization of group activities has been placed on powertrain sizing and selection, body / chassis materials selection and architecture, and powertrain integration.

QUALITY FUNCTION DEPLOYMENT MATRIX																					
PRODUCT LINE ==> Hybrid Bus	ETEC-344 - INDUSTRIAL QUALITY ASSURANCE																				
MAJOR SUBSYSTEM ==> Interior																					
CHARACTERISTIC	CUSTOMER REQUIREMENTS	PRIORITY {1-5; 5 = High}	DESIGN SOLUTIONS	Centrally Located Driver	Forward Placed Driver	Driver Concave Mirror	Minimize Height Obstructions	Driver Adj. CoreWorks Chair	Drive By Wire	Easy Acces To Controls	Optimized Wheelchair Ramp	ADA Compliant (Aisles and Access)	Strategically Located/Properly Sized E-Ex	Wired Options	Adjustable Seats/Foot Rests	Grab Handles for 15th Percentile Height	Fare Box in Close Proximity to Driver	Low Ride/ Floor	Proper Window Seals/Side Wall Insulatior		
Bus Interior	DRIVER																				
	Road Visibility	5		9	9	1	9	0	0	0	0	0	3	0	0	0	0	0	0		
	Passenger Visability	3		3	3	9	9	0	0	0	0	0	0	0	1	0	0	0	0		
	Comfort/Ergonomics	4		3	3	9	0	9	9	9	9	0	0	0	0	0	0	0	0		
	Vehicular Interface	4		9	9	3	0	3	9	9	1	0	0	0	0	0	1	0	0		
	Safety	5		1	9	9	3	1	3	3	1	1	9	0	0	0	0	0	0		
	Disabled Passenger Accommodation	5		0	0	0	0	0	0	0	9	3	3	0	0	0	0	0	0		
	PASSENGER																				
	Disabled Access Improvements	3		0	0	0	0	0	0	0	9	9	0	0	0	1	3	9	0		
	Emergency Exits/Survivability	5		0	0	0	1	0	0	0	0	9	9	0	0	0	0	0	9		
	Luxury Amenities	2		0	0	0	0	0	0	0	3	0	0	9	0	0	0	0	0		
	General Ergonomics	3		0	0	0	1	0	0	0	3	0	0	0	9	3	0	3	0		
	Easy Access	5		0	0	0	0	0	0	0	9	9	3	0	0	0	1	9	0		
	External Sound Dampening	3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9		
	FLEET OPPERATOR																				
	Durability	5		0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0		
	Light Weight	2		0	0	0	0	3	3	0	0	1	0	0	0	0	0	0	0		
	Serviceability	5		3	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0		
	Survivability	5		1	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0		
	Maintenance (Hoseability)	4		1	0	3	0	3	1	0	0	0	0	0	0	0	0	0	0		
	Maximum Seating	5		0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
TECHNICAL DIFFICULTY {1-5; 5 = High} ==>				5	3	1	3	3	4	2	2	3	2	2	3	1	2	3	2		
	OBJECTIVE TARGET VALUES ==>																				
	OBJECTIVE MEASUREMENTS ==>	US																			
		C1																			
		C2																			
		C3																			
TECHNICAL IMPORTANCE { Sum (Priority x RM) } ==>				122	147	125	95	59	93	132	177	139	135	18	30	12	18	81	72	0	0

RELATIONSHIP MATRIX {9, 3, 1, 0; 9 = Strong}

CalStart/WestStart Hybrid Truck Users Forum (HTUF) Fleet Operator Criteria Rating

Performance Criteria	Overall Ranking
Reliability ≥ base vehicle	1
≥ 30% better fuel economy vs. base vehicle	2
Serviceability/maintain-ability ≥ base vehicle	3
Chassis Durability ≥ base vehicle	4
Range ≥ 300 mi	5
Lifecycle costs ≤ base vehicle	6
Emissions < base vehicle	7
Life in Years ≥ base vehicle	8
Interior noise level ≤ base vehicle	9
passenger capacity due to hybrid drive system	10
Acceleration ≥ base vehicle	11
Weight penalty of hybrid drive system components ≤ 500 lbs	12
Driver ergonomics ≥ base vehicle	13
Gradeability ≥5% @ 40 mph @ GVW	14
Exterior noise level ≤ base vehicle	15
Startability ≥ 25% grade	16
Front axle turning radius ≤ base vehicle	17
Approach angles to curb ≥ base vehicle	18
No reduction in ground clearance due to hybrid	19
Top Speed ≥ base vehicle	20
Stay within base vehicle width dimensions	21
Stay within base vehicle height dimensions	22
Keep existing body supplier	23
Keep existing engine supplier	24

Figure 2 – Quality Function Deployment Matrix for Hybrid Bus Interior

Vehicle Performance Modeling

A basic road load analysis model has been developed to assist with characterization and refinement of design details associated with gross vehicle weight, aerodynamic drag, and rolling resistance, which are critical to vehicle operating efficiency and performance. The tool also helps with analysis of hybrid and pure electric powertrain design by estimating required SI or CI engine and electric motor power requirements, as well as battery pack size, weight and cost. The analysis considers vehicle weight targets, tire rolling resistance, coefficient of drag, frontal area and drivetrain efficiency, among other characteristics. Initial road load analysis has confirmed that the targeted Subaru 2.5L naturally aspirated IC engine rated at 127 kW (170 hp) in combination with a 145 kW (195hp) DC electric motor will provide sufficient power to meet desired launch and cruise performance targets. The Subaru boxer style IC engine was chosen due to its horizontally opposed piston geometry, which results in a low profile architecture that is favorable for minimizing vertical packaging space claim. This will allow for minimal intrusion into the passenger compartment, which will in turn, maintain targeted overall vehicle geometry. Specifically, the intent is to place the powertrain in the rear of the vehicle while incorporating the rear-most seats over the top of it and maintaining disabled passenger access. Low profile powertrain packaging is critical when dealing with design constraints associated with the low floor architecture.

The initial proof-of-concept parallel hybrid vehicle will target a powertrain control strategy that is vehicle speed and throttle position defined. Under light throttle launches and low operating speeds, the electric motor will provide motive power, which is where it is most efficient due to its high torque at low speed operation. When heavy throttle position is sensed, the IC engine will combine with electric power to move the vehicle. At higher cruising speeds the electric motor will shut off and the vehicle will run solely on the IC engine, which is where it operates the most efficiently. The IC engine was sized to accommodate road load demands at higher speeds when aerodynamic drag is greatest. Analysis indicates that at a rated GVW of 6220 kg (13700 lb) and with a non-optimized frontal area of 7 m^2 (76 ft^2), at maximum cruising speed of 113 kph (70 mph), 106 kW (142 hp) is required to maintain velocity. This value includes a 15% allowance for simultaneous generator draw, to enable battery charging while powering the vehicle. The targeted IC engine has sufficient capacity for this requirement. Initial goals provided by the primary customer base indicate a 320 km (200 mi) cruising range between refuel and/or recharge. The HTUF group has placed a more demanding target of a 480 km (300 mi) cruising range, which has been incorporated as the benchmark. This goal will be achievable through the proposed hybrid system.

Analysis was also conducted for battery pack power and size requirements based on targeted all-electric cruising range and initial vehicle architecture. These values are then compared with the various battery technologies to estimate battery pack weight, volume and cost. The tool allows various scenarios to be quickly performed to determine basic vehicle parameters. Kitsap Transit has donated a 2001 APS Electric Bus to WWU to aid the R&D team as a benchmark tool. In Table 1 below, the 7713 kg (17,000 lb) APS Electric Bus is compared to a proposed vehicle specification for road loads at 48, 81, and 113 km/hr (30, 50, 70 mph).

Table 1 – Road Loads for APS Electric Bus vs. Low Weight Hybrid Bus

Vehicle Weight Lbs	Kg	Road 0.015 Fr*W lbs.	Road Load N	Aero Loads Cd	Frontal Area ft^2	Area m^2	Vehicle Speed Kph	Vehicle Speed mph	Aero Drag lbs.	Aero Drag N	Total Road Load Lbs	Total Road Load N
8000	3630	120	534	0.3	42	3.9	48	30	29	128	149	662
8000	3630	120	534	0.3	42	3.9	80	50	80	356	200	889
8000	3630	120	534	0.3	42	3.9	113	70	157	697	277	1231
17000	7713	255	1134	0.4	78	7.25	48	30	71	317	326	1451
17000	7713	255	1134	0.4	78	7.25	80	50	198	881	453	2015
17000	7713	255	1134	0.4	78	7.25	113	70	388	1726	643	2860

Table 1 shows that the 3630 kg (8000 lb) bus with improved aerodynamics and reduced frontal area uses less than half of the energy required to power it at 80 kph. As a direct result, the battery pack required to travel 81 km (50 mi) at a speed of 80 kph (50 mph) will be less than half as large; 23 kWh vs. 53 kWh for the larger APS Electric Bus model as shown in Table 2 below. If an all electric range of 81 km (50 mi) is a reasonable goal, then the smaller bus will require a battery pack that is less than half the size, weight and cost of the larger vehicle's pack.

Table 2 – Energy Demands for APS Electric Bus vs. Low Weight Hybrid Bus

ENERGY in KWH

POWER HP	kW	Efficiency Wh/mi	"@ RANGE in km and miles 48 / 30	80 / 50	161 / 100	241 / 150	322 / 200	Vehicle Speed Kph	Vehicle Speed Mph
14.1	10.5	350	10	17	35	52	70	48	30
31.5	23.5	470	14	***23***	47	70	94	80	50
61.0	45.5	650	20	33	65	98	130	113	70
30.8	23.0	767	23	38	77	115	153	48	30
71.4	53.2	1065	32	***53***	106	160	213	80	50
141.8	105.8	1511	45	76	151	227	302	113	70

In Table 3, estimates for battery weight, volume and cost are provided for lead acid batteries (SLA), nickel cadmium (NiCd), nickel metal hydride (NiMh) and lithium ion (Li-Ion). Data for the lead acid, nickel cadmium and nickel metal hydride batteries are based on packs used at the VRI. The lithium ion values are estimates based on the likely technologies available for large packs.

Table 3 – Estimates for battery cell unit weight, volume and cost

BATTERY DATA

	ED WH/kg	VED WH / l	VED MJ/ l	COST $/KWH
SLA	28	75	0.27	200
NiCd	48	100	0.36	300
NiMh	70	200	0.72	400
LI-Ion	175	400	1.44	1000

(ED = Energy Density; VED = Volumetric ED)

For a given all-electric range target or for charge depleting operation on a hybrid drive cycle, the battery weight, size and cost may now be estimated. In Table 4 below, the NiMH technology is compared to Li-Ion for both the APS bus and the proposed low-mass hybrid bus with a range of 80 km (50 mi). This type of analysis provides a basis for discussing the trade-offs between hybrid vs. all-electric. When combined with specific bus route information, this can help provide boundaries for the bus design for overall budget and to guide infrastructure decisions for charging station locations.

Table 4—Battery Pack Size, Mass and Cost for 80 km Range.

	Volume, L	Mass, kg	Cost, $
Hybrid Bus Pack NiMH	117	336	$9,400
Hybrid Bus Pack LiIon	59	134	$23,499
APS Electric Bus NiMH	266	761	$21,294
APS Electric Bus LiIon	133	303	$53,235

These estimates are used in the early design phases. When battery life is considered as well, a pack roughly 80% larger in terms of energy (kWh) is chosen to improve the number of cycles available from each pack. This approach provides design targets for our fuel-efficient hybrid vehicle to achieve. With a 3630 kg (8000 lb) curb weight, a frontal area half the standard bus at 3.9 m^2 (42 ft^2), and a more efficient form, the design team should be able to achieve the desired fuel efficiency goals.

Body and Chassis

The hybrid bus will benefit from the composite manufacturing process developed for the Viking 40 and 45 chassis and body structures. A one piece composite body section is bonded and fastened to a thin floor section that includes suspension, engine and seat mounts. The body provides the primary stiffness and strength for the entire vehicle. A vacuum assisted resin transfer process (VARTM) provides good fiber to resin ratio for high specific strength. The process allows dry reinforcement fibers such as fiberglass or carbon fiber to be placed under vacuum before the resin matrix is drawn through the fibers. Experience with the Viking 40 and 45 vehicles has demonstrated that an entire raw body could be infused with resin, cured, and de-molded within a few hours. A post-curing operation conducted at 100 ˚C would improve the mechanical properties, but also extend the mold time. Similar to Viking 40 and 45, a four millimeter core sandwiched between one millimeter layers of composite fiber could form most of the body structure, with local reinforcement for windows, side impact structure and roll-over protection for the bus. Considerations for the larger vehicle mass, greater payload and sound-proofing requirements will likely increase the wall structure section thickness; however, this laminate structure has been successfully implemented in many load bearing applications. Comparable stamped steel body panels for a vehicle of approximate external measurements of the hybrid bus (37 $m^{2,}$ or 396 ft^2) would contribute approximately 440 kg (970 lb) to the overall vehicle mass, versus an equivalent carbon fiber composite structure of 187 kg (412 lb) to 225 kg (495 lb). An entire body and chassis structure could be less than 450 kg (990 lbs). This type of structure can meet the low mass goals required for improved fuel economy with sufficient impact and structural strength.

Alternative construction methods include a body-on-frame approach, using composite braided frame rails. The braided frame rail approach could potentially increase chassis mass, and direct the design toward more conventional architecture, yet the loading requirements may dictate this methodology. One of our manufacturing partners, Composite Manufacturing Technologies, is a technology innovator in composite structural frame braiding technology for the aerospace industry, and promises to be a strong consultant for design optimization in this area, should this path be required. Presently, the monocoque design approach is favored due to its ability to improve structural rigidity and reduce weight by integrating the chassis and body. Additionally, the monocoque design could allow for improved battery pack storage under perimeter style seating, though our primary fleet customer group discourages anything but forward facing seats, due to the tendency for motion sickness on longer trips with side facing seat designs. Preliminary monocoque chassis designs have been completed, with finite element analysis (FEA) and design optimization targeting completion by the spring of 2010.

While carbon fiber is widely available, and is planned as a back-up material for the first prototype vehicle, it presents a means for increased production material costs down the road, as petroleum and its derivatives continue to rise in price due to increasing global demands and a finite oil reserve base. Likewise, petroleum based polymers will see similar price increases in the future. In his book "The Long Emergency", and as many others continue to stress, James Howard Kunstler indicates the need to move away from our dependency on foreign oil and to prepare for the inevitable depletion of available petroleum reserves. According to Kunstler, "… worldwide discovery of oil peaked in 1964 and has followed a firm trend line downward ever since…[and] the United States passed peak in 1970 with the annual rate of production falling by half since then… the ratio of energy expended in getting the oil out of the ground to the energy produced by that oil in the U.S. oil industry has fallen from 28:1in 1916 to 2:l in 2004 and will continue falling."[8] The projected upward trend of petroleum prices and its effect on the price of carbon fiber materials for vehicle manufacturers will most likely make it a desired material that is, unfortunately, cost prohibitive.

Carbon fiber based composites are currently used in the aerospace industry, as well as higher cost, performance vehicle applications. The WWU VRI has significant experience with this material and associated processes in the construction of their previous passenger car applications. As of the date that this paper was written, carbon fiber fabric was priced at approximately $40 per pound[9], which represents a value that is twenty times that of current steel prices[10]. Its sustainability characteristics are further compromised by its inability to recycle to a full strength material application. When bonded and cured carbon fiber is ground up for recycling, the strength of initial long fiber orientation is disrupted, with resulting shorter fiber matrices being unable to meet original strength values. With the assistance of our industry representative group, the R&D team is pursuing the feasibility of using thermoplastic composites. Transition Composites Engineering has recently completed a project in which E-glass thermoplastics were successfully used for the construction of a long-haul semi-trailer chassis. Glass reinforced thermoplastics represent a viable alternative in that they provide a cost advantage at $8 per pound[11], are recyclable for continued use, and present a range of material grades for interior and exterior components.

As conventional thermoplastics remain petroleum based, the WWU R&D team continues to explore alternative natural fiber and bio-fiber based materials, as well. If a carbon fiber based vehicle is retired from service, the body panels and chassis are not readily reusable or recyclable, and would require further processing and costs to enable reuse in less durable goods applications. If the composite components are not reused they could contribute toward ever-increasing solid waste landfill concerns. In order to provide a concept vehicle that demonstrates practical design architecture made from sustainable materials, the WWU R&D team is investigating the use of renewable source biopolymers and bio-fibers. According to Bledzki, et al. " …automotive industries have been using bio-fibres for interior components for several years… [interior] door panels of the Ford Mondeo are manufactured by kenaf reinforced polypropylene… nowadays bio-fibre composites are also used in the exterior components [no elaboration / examples]… [and] 27 components of [the 2006 Mercedes S Class]…are manufactured from bio-fibre reinforced composites."[12] The feasibility of bio-fiber based materials and their application to structural components will continue to be a critical area of research for the R&D team, and will require the assistance of the Chemistry and Plastics Engineering groups present on the WWU campus. Factors that need to be scrutinized before proceeding with bio-based materials include raw material conversion costs, mechanical property comparisons with specific compound chemistries, manufacturing process controls, and a means for controlling the potential for premature biodegrading when exposed to the environment during their useful lifecycle. An additional factor for research will be the development of bio-resins with sufficient bonding strength for structural application. The inclusion of high strength, low density, and renewable material options will remain a focus for the team.

Strength values for structural steel materials vary based on alloy chemistries, as do composite material matrices and their respective chemistries. The median ultimate tensile strength values and associated densities for materials being evaluated for the hybrid bus project are presented in Table 5. Conventional steel and aluminum values are provided as a baseline for comparison to carbon fiber, bio-fiber, and glass reinforced thermoplastic materials. The strength values for flax are surprising, and make it a preferred choice from a sustainability view point; however, due to the lack of successful production implementation examples in structural components, and the degree of inconsistent natural fiber structures, the research and development activity associated with these materials may prove to be too intensive to be included in the first prototype vehicle, due to timing concerns. Thermoplastics, in the form of E-glass and S-glass variants provide strong options for structural materials, and are currently the material of choice for chassis and body components. E-glass is electrical grade glass which constitutes the primary reinforcing fiber in conventional fiberglass. S-glass is a toughened version of E-glass with more than 50% greater tensile strength due to the increase of silicon dioxide and aluminum oxide compounds. Final material selection will depend on results of structural analysis, continued research efforts, and the availability of raw materials for testing and processing. Acquisition of natural fiber materials has been a challenge thus far.

Table 5 – Comparison of Potential Structural Materials

Property	**Units**		**Steel**[8]	**Aluminum**[8]	**Carbon Fiber**[7]	**Jute**[10]	**Hemp**[10]	**Flax**[10]	**E-Glass**[10]	**S-Glass**[10]
Density	(g/cm^3)		7.85	2.7	1.6	1.46	1.48	1.4	1.8	2.0
Ult. Tensile Strength	(Mpa)		960	255	1400	600	725	1150	700	1100

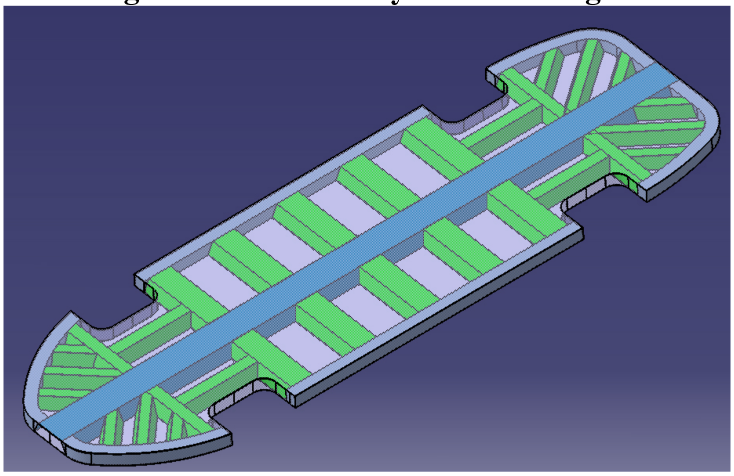
A comparison of seating design layouts is in process, and is targeted for completion during the winter of 2010. The possibility of integrated seating banks will be investigated to further improve structural stiffness, and to allow for minimum battery storage system intrusion into the passenger compartment. Perimeter seating is currently used in many transit vehicles, including the 2001 APS Electric Bus, previously mentioned. While the APS bus took the minimalist approach to seating design by using a hollow shell that was lightly padded at the passenger interface point, the WWU R&D Team seeks to enhance passenger comfort through the use of ergonomically designed seating that allow for adjustability, where feasible. This is an area that requires further analysis; however, the goal of interior modularity and the concern for motion sickness associated with side facing seating will most likely inhibit in-molded seating along the sides of the vehicle. Based on current design direction, the plan is to place the IC engine powertrain in the rear of the vehicle. The need for packaging space will intrude upon the interior passenger compartment, which may allow for in-molded seating along the back of the vehicle. This will allow for necessary strengthening of the rear hull section, while simultaneously optimizing engine compartment and passenger seating space in the rear of the vehicle.

Design investigations associated with the external structure will include alternative passenger and driver access methods, which are intended to address the conventional step designs and related trip-hazard concerns, as well as improving disabled passenger accessibility. The primary customer base has requested a low floor design approach, which targets a step height of less than 280 mm (11 in). Retractable ramp designs in combination with a turntable style floor insert are under investigation, and will improve wheelchair access and mobility, as well as reduce potential trip hazards. Low floor designs come with a range of design challenges which include ground clearance reduction, drive axle location restrictions, floor structure considerations, and suspension system complexity. Based on the current composite floor sectional thickness and the goal of minimizing vehicle frontal area, the low floor requirement will most likely dictate the need for a "kneeling" or adjustable height suspension system to accommodate the low entrance requirement while maintaining adequate ground clearance for the range of anticipated terrain the vehicle will encounter.

Vehicle drag coefficient values will be improved over current "bread box" shaped designs, through reduced frontal area. Currently, a high center aisle, with lower "shoulder" heights above seated passengers' heads is the preferred frontal profile, resulting in an estimated 25% reduction in frontal area. Based on findings by Williams et al. in 1999, "…there appears to be a very clear trend - higher aspect ratio (i.e., taller) vehicles have lower Cd values."[13] This supports the proposal for a higher center section, while avoiding a negative impact on overall aerodynamic drag coefficient. Additionally, a combination of design aspects will allow for placement of the driver at a centrally located vantage point. The monocoque body / chassis concept continues to progress and includes a centralized, airplane style cockpit architecture, with resultant improved driver visibility for both front vehicle corners. This will address fleet operator concerns for curb-side corner scrub when picking up passengers. Additional design considerations include maximizing passenger viewing space, while maintaining sufficient structural support for side impact and roll-over occupant protection. A preliminary chassis design is in process, and reflects a reinforced sandwich structure, shown in Figure 3. The figure represents the base footprint of the vehicle, and provides for a smooth transition to the body structure. The current approach utilizes the two-dimensional "skateboard" chassis design that blends into the main body for transition into a monocoque structure, taking cues from airliner fuselage construction. The design extends the lateral floor supports to form radial ribbing which continue up the walls and joins at the roof, forming continuous ribs, and providing critical stiffening members for the overall structure. Figure 4 indicates the extension of the composite chassis as it forms to create the monocoque structure. Figure 5 represents one of the proposed body configurations which will be further optimized through Finite Element Analysis (FEA) and scale model wind tunnel testing. Chassis and body designs have been developed by the students, and will be further refined based on interior and powertrain packaging detail requirements.

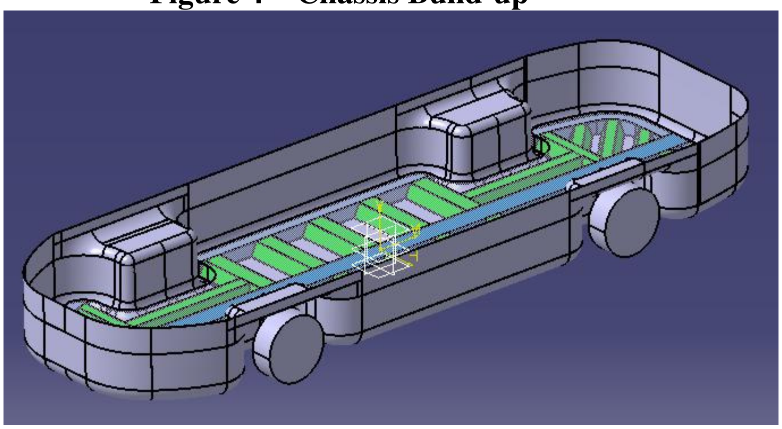
Maintaining a design for manufacturability approach, consultation with our industry representatives has confirmed current plans to split the monocoque structure laterally at a point between the seating and window lines. This will facilitate construction of a two-piece molding tool, with consideration for post-molded part extraction.

Figure 3 – Preliminary Chassis Design



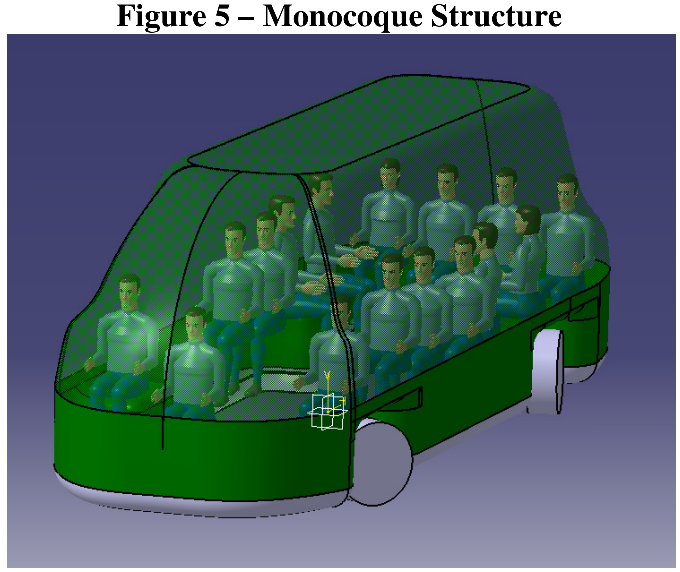
Provided by Eric Grimstad – WWU CAD/CAM Major

Figure 4 – Chassis Build-up



Provided by Eric Grimstad – WWU CAD/CAM Major

Figure 5 – Monocoque Structure



Provided by Eric Grimstad – WWU CAD/CAM Major

Powertrain System Architecture

For sustainability, it is important that the regional infrastructure will be able to provide feedstocks for alternative fuel production and continued consumption. Examples of regional feedstocks in the Pacific Northwest include processed methane from agricultural and municipal waste, and biodiesel produced from select crop farming. In keeping with the goal of powertrain modularity to enable regional fuel source utilization, the WWU R&D team continues to analyze design options that are capable of supporting regional fuel usage while minimizing expensive vehicle hardware changes. This also supports the initial targeting of the 4-cylinder Subaru IC engine which will allow for minimal hardware reconfiguration when building either the 2.5L spark ignition engine or 2.0L compression ignition engine, based on consumer needs. Through provision of modular powertrain integration hardware, the vehicle can be built to suit the fleet operator's needs, with minimal revision to assembly plans. The ultimate goal is to be able to provide a spark ignition or compression ignition internal combustion (IC) engine that matches the regional fuel availability, and allows for increased driving range on a combined IC engine fill-up and battery recharge. Additionally, as expressed by several operators attending the workshop, a desire for 100% electric capability will be met through deletion of the IC engine option, and increasing the battery pack size. While it is apparent that this could significantly impact the vehicle cruising range, based on specific transit routes, the ability to recharge after reaching critical discharge levels could be planned for.

Series and parallel hybrid powertrain configurations have their advantages and disadvantages. In a series hybrid, the IC engine does not power the wheels, but serves to generate electrical power for on-the-road battery charging. One advantage for the series configuration is that the IC engine is set up to constantly run at its most efficient speed, thereby reducing specific fuel consumption, and optimizing efficiency; however, inefficiencies associated with the conversion of mechanical to electrical power are of major concern. A parallel hybrid powertrain has the ability to utilize electric, IC engine, or a combination of both power sources, based on vehicle demands; however, the primary concern of increased mass due to the potential need for two "independent" drivetrain systems exists. Both configurations have been successfully built and implemented at the WWU VRI and in the industry. An alternate configuration that is currently utilized in recent mainstream hybrid vehicles, such as the Toyota Prius, is the powersplit configuration. In this hybrid arrangement, similar to the parallel design, the vehicle can be powered by the electric motor, the IC engine, or a combination of the two, depending on power demands. Additionally, based on incorporation of a second electric motor that serves as a generator, the IC engine can be driven to power the electric generator, which in turn stores energy in the battery packs. During normal operation, a fraction of the IC engine power is used to constantly charge the batteries in addition to the braking energy that is normally lost but is recaptured through the regenerative braking function. The powersplit approach provides an effective alternative to the series / parallel conundrum that continues to challenge mainstream hybrid vehicle manufacturers.

Fleet operators and drivers have indicated the need to remain with automatic transmissions based on ease of use and service. Contained in the vast majority of public transit vehicles on roads in the US today, typical automatic transmissions are heavier than their manually shifted counterparts, and possess an inherent inefficiency in operating speeds lower than the point of torque converter lock-up. Conventional torque converter and automatic transmission systems do not lock up until running in upper gear positions, or higher operating speeds (ie. above 40mph, or in overdrive). During stop and go urban cycles, the torque converter does not often see operating speeds high enough to allow for lock up, thus it is constantly running in the reduced efficiency "slip" mode present in lower gears. Planetary gear arrangements within the infinitely variable transmission (IVT) provide a "geared neutral", thereby eliminating the need for a start clutch, as used in manual transmissions, and can eliminate the inefficient torque converters used in typical automatic transmission applications. Based on initial evaluations with an IVT in place of a 5-speed automatic transmission, "Torotrak, …[developers] of full-toroidal traction drive technology, and Optare UK, one of Europe's top bus manufacturers, have recently achieved an outstanding 19% fuel economy improvement in an [11,300 kg (24,900 lb), 60- passenger] Optare Solo Bus."[14] These results were achieved prior to application tuning, and Torotrak anticipates an additional 4% gain based on computer models. We currently possess a transaxle generator from a 2005 Toyota Prius that we are analyzing and benchmarking for system design of the bus drivetrain. Based on initial analysis, further research of IVT implementation is required to determine if weight and cost aspects will fit within the overall project goals for the hybrid bus vehicle. The R&D team has determined that the powersplit configuration will be the design direction, and will look to optimize and adapt new technology to the bus application.

Through the combination of reduced vehicle mass, improved aerodynamics, and the hybrid powertrain system, the team feels that the fuel economy target of 11.7 l/100 km (20 mpg), which represents an increase of 120% above current Kitsap Transit fleet average fuel economy values, is very achievable. Through utilization of the IVT drivetrain, operating engine speeds can be targeted that represent the best specific fuel consumption values for the selected IC engine. This is done by mapping the engine for fuel consumption values under a range of operating conditions, and finding the speed range (engine rpm) that delivers the best fuel economy levels. The IVT can then be tuned to maintain this engine rpm for the majority of torque demand scenarios.

Preliminary analyses indicate minimum power requirements of 100 kW (134 hp) electric motor and a 110 kW (148 hp) internal combustion engine, which can be obtained from current production manufacturers. The Powertrain Sub-group within the R&D Team has been tasked with selecting viable IC engines and electric motors that represent latest technology and maintain weight and efficiency goals. Based on performance, weight and cost parameters, the group is focusing on lightweight 4-cylinder compression ignition and spark ignition engines with the latest emission controls technology, which are available from a range of mainstream engine manufacturers. The R&D Team is currently targeting Subaru naturally aspirated IC engines for powertrain modeling due to their relatively low vertical height space claim, and reduced intrusion into the passenger compartment. Improved fuel economy and wide commercial availability make these engines good candidates for the hybrid bus. Concerns with these engines are limited to duty cycles associated with high-mileage, stop-and-go traffic, and their ability to support the higher GVW's associated with this application. Subaru is marketing a 2.0L CI engine in Europe, and is looking to bring this product to the US in 2011. Through the use of a common engine support cross member, the hybrid bus could be equipped with either SI or CI engine options, enabling it to maintain the goal of multiple alternative fuel options.

Table 6 - Powertrain Options Summary

Hardware Configuration	Positive Aspects	Negative Aspects
Conventional SI V-6 / V-8 Engine	- Sufficient Power Capacity - High Mileage Durability	- Poor Fuel Economy - Heavyweight - Packaging Concerns
Boxer SI 4-Cylinder Engine	- > Fuel Economy - Lightweight - Packaging	- High Mileage Durability Concerns - Insufficient Power @ Peak Demand
Boxer CI 4-Cylinder Engine	- > Fuel Economy - > Power Density - Lightweight - Packaging	- > Emissions - High Mileage Durability Concerns - Insufficient Power @ Peak Demand
Conventional Automatic Trans.	- Ease of Operation - Commercial Availability	- Heavyweight - < Fuel Economy
Conventional Manual Transmission	- > Fuel Economy - Commercial Availability	- Complex Operation in Stop & Go Traffic - Clutch Service for > Stop & Go Traffic
Infinitely Variable Transmission	- Ease of Operation - > Fuel Economy	- Limited Commercial Availability
100% Electric Drive	- Zero Vehicle Emissions - No Petroleum Based Fuels	- Large Battery Pack & Assoc. $ - Inability to Meet 300 Mile Cruise Range Target Cost Effectively
Hybrid Drive System	- Sufficient Power Capacity - > Fuel Economy - < Vehicle Emissions	- Heavyweight - Complex Powertrain Controls

Fuel for Thought

Alternatively speaking, the fuel for the secondary power source IC engine for the first prototype vehicle has been narrowed down to two options; biodiesel and biomethane. Either fuel has great potential from an energy density standpoint, with biodiesel at 118,300 btu/gal[15] and biomethane at 56,350 btu/gal, compared to 125,000 btu/gal and 129,500 btu/gal for typical gasoline and diesel fuels, respectively.[16] The decision came down to these two options based on relative cost, IC engine conversion simplicity, current regional fleet operator access, and potential for long term sustained infrastructure support. Biomethane offers an advantage with lower emissions, reduced carbon footprint, and lower fuel unit cost. Disadvantages include increased fuel tank volume and increased infrastructure cost. In an alternate project, the WWU VRI is developing an on-site biomethane refining system for a local dairy farm in Lynden, Washington. A potential exists for applying this technology to a municipal project between Kitsap Transit and a local sewage treatment facility. The initial prototype vehicle will likely utilize a bio-methane / electric hybrid configuration, however, as the vehicle nears completion, the ability to adapt to biodiesel fuel is available, and will further demonstrate the capability for modular design and fuel selection.

Summary

It is difficult to summarize the hybrid bus project at this point, as the R&D team continues to enhance the design based on ongoing research activity. It can be stated that the WWU R&D team continues to enthusiastically contemplate the future of this design, which may very well represent the future direction of the public transit market, as the industry seeks to resolve the answers to the finite natural resource dilemma we are facing. This project is a valuable prelude to the inevitable issues this generation of engineers will need to resolve. By collaborating with transit agencies such as Kitsap Transit, we are able to offer a viable solution to the market that is not just a means to resolve fuel concerns, but simultaneously addresses the needs of all involved with public transit. The design methodologies and innovations, as well as manufacturing processes and technology applications will be handed off to a capable production source that will take the concept into volume production. Production planning of the hybrid bus will be the final phase of the R&D team project. This will then allow the WWU VRI tradition of designing and fabricating innovative mobility solutions to continue on to the next project. Personal mobility…levitating vehicles…next generation mass transit…the options are limited only by the imagination of these future engineers!

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Appendix A – Western Washington University Hybrid Bus Project Preliminary Specifications Sheet

HYBRID BUS PRELIMINARY DESIGN SPECIFICATION SHEET

		US				ISO					
Component Group	**Characteristic**	**Max.**		**Min.**		**Max.**		**Min.**		**Benchmark**	**Comments**
Exterior	Length	22	ft			6.7	m				Workshop fleet operator target not to exceed 25ft
	Width	8	ft			2.4	m			WWU E-Bus	
	Height	9.5	ft			2.9	m			WWU E-Bus	
	Frontal Area	57	ft^2			5.3	m^2			WWU E-Bus	Target $\geq$ 25% reduction over E-Bus (76 ft^2 or 7.1 m^2)
	Drag Coefficient	0.40									
	Curb Weight	**8000**	lb			3629	kg			WWU E-Bus	** Need to obtain realistic TPC mass for reduction in GVW; E-Bus @ 17,000lb w/ batteries
	GVW	**13000**	lb			5897	kg			StarTrans Senator	Curb weight + (17 seated +7 standing + driver) => reduce based on < curb weight; STS = 14500lb
	Tire Size	235/60R18								StarTrans Senator	** LT225/75R16 => 708rpm @45 mph- Standard; need low rolling resistance
	Rollover Crush Stiffness										
Chassis	Weight	4000	lb			1814	kg			Ford E-450 Cutaway	Stripped Chassis => 6130lb / 2781 kg
	Stiffness										
	Wheelbase	176	in			4.5	m			StarTrans Senator	
	Front Track Width	69.4	in			1.8	m			Ford E-450 Cutaway	
	Rear Track Width	77.7	in			2.0	m			Ford E-450 Cutaway	Dual rear tire usage
	Suspension Travel										
	Ground Clearance										
Interior	Floor Height	11	in			0.3	m				
	Standing Row Ceiling Height			80.5	in			2.0	m	StarTrans Senator	Ford E-540 cutaway chassis
	Seated Ceiling Height										
	Seating Capacity	17		15						Kitsap Transit	
	Standing Capacity			7						Kitsap Transit	
	Wheelchair Capacity	6		2						Kitsap Transit	
	Storage Capacity										
	Viewing Surface Area										
	Floor Loading Capacity										** Need contact patch for wheelchair
	Emergency Exit Space										
Performance	Fuel Economy			20	mpg			11.8	l/100km	Kitsap Transit	+100% improvement over Kitsap Transit fleet average
	Acceleration	18	s								0-60 mph @ SLW (seated load weight)
	Gradeability			==>						HTUFF RFP	5% @ 40mph @ GVW
	Braking									Ford E-450 Cutaway	4-wheel disc w/ 13.58" rotors
	Cruise Range			300	mi			483	km	HTUFF RFP	Combined electric / fuel range on one charge / fill
	Turning Radius	**25**	ft	31.25	ft	7.6	m	9.5	m	Ford E-450 Cutaway	Wall to wall; Max = Workshop target; Min = E-450 baseline
	Top Speed			70	mph			113	kph	HTUFF RFP	
Sustainability	Design Complexity										
	Materials Biodegradability										
	Materials Recyclability										
	Product Manufacturability										
	Product Servicability										
	Configuration Flexibility										
Cost	Body / Chasssis										
	Powertrain										
	Interior										
	Communications										

Appendix B – Western Washington University Hybrid Bus Project Preliminary Features List

HYBRID BUS FEATURE LIST
as of 8/14/09

Item #

Standard Features

Item #	
1	Powersplit Hybrid Powertrain {Customer Selected IC Engine}
2	4-Wheel Adjustable Independent Suspension
3	4-Wheel Steering
4	Electronically Controlled Passenger Entrance Door
5	ADA Compliant Entrance / Aisle Way / Seating / Emergency Exits
6	235/60R18 Low Rolling Resistance Tires + Full Size Spare
7	Electronically Adjustable Driver Seat
8	Driver Blue-tooth Communications System
9	On-board Vehicle Diagnostics System
10	Overhead Passenger Storage System
11	Modular (15) Occupant Seating {Driver + (12) ambulatory + (2) wheelchair positions}
12	Common Area Large Item Storage Compartment
13	6-Speaker Stereo / Public Address System
14	Climate Control System
15	Driver Rear View Projection System
16	Individual Passenger Lighting / Vent Controls

Optional Features

Item #	
17	100% Electric Drive
18	4-Wheel Traction Control
19	Solar Powered Auxiliary Electric Power System
20	On-board Infotainment System (Wi-Fi, Seat Monitors, Premium Power Outlets)
21	Digital Passenger Fair Box
22	Modular (17) Occupant Seating
23	Rear-mounted Bicycle Rack
24	Compact Lavatory