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Development of a Lightweight Electric Urban Delivery Truck

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July 2007

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by
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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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16. Abstract

This project was part of the development of an aerodynamic, all-electric, composite monocoque urban delivery truck named the QuickSider™ intended to meet the requirements of Purolator Courier Ltd. It had two objectives:

1. To complete the structural design of the lightweight composite monocoque low-floor body, and
2. To explore the electric drive options to provide it with a zero emission vehicle range of 120 km.

A computer-aided design (CAD) model of a full-scale mock-up was developed using finite element analysis (FEA). A physical full-scale mock-up was then built and tested structurally. Alternative floor structures were assessed. The results were used in the structural design of a working prototype. A CAD model for a prototype was developed using FEA, with particular focus on high stress areas.

A statement of requirements for the truck's battery system, based on the truck's physical and operational requirements, was prepared and issued to several potential battery suppliers, and the responses analyzed. The conclusion was that a system based on MES-DEA's Zebra battery was the only viable solution then available.

A working prototype was built and subjected to extensive testing. No unacceptable stresses, deflections or resonances in the structure were identified. The vehicle's performance was generally consistent with design expectations.

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16. Résumé

Cette étude est une composante d'un projet de développement d'une camionnette de livraison légère tout électrique pour milieu urbain baptisée QuickSider™, à carénage aérodynamique et à carrosserie monocoque en composite, conçue pour répondre aux besoins de Purolator Courrier Ltée. Deux objectifs étaient poursuivis :

1. mener à terme la conception structurale de la carrosserie monocoque légère en composite, à plancher bas;
2. étudier les options en matière de propulsion électrique, pour doter la camionnette d'une autonomie de 120 km en mode véhicule à émission nulle.

Un modèle CAO (conception assistée par ordinateur) d'une maquette grandeur réelle a été développé au moyen d'une analyse par éléments finis (AEF). Une maquette physique grandeur réelle a ensuite été construite et soumise à des essais de structure. Plusieurs variantes de structures de plancher ont été évaluées. Les résultats ont servi à la conception structurale d'un prototype fonctionnel. Un modèle CAO du prototype a été développé au moyen d'une AEF, une attention particulière étant portée sur les zones sujettes à de fortes contraintes.

Un énoncé des besoins concernant les batteries a été rédigé, d'après les caractéristiques physiques et les conditions d'exploitation de la camionnette, et il a été transmis à plusieurs fournisseurs de batteries potentiels. Après analyse des réponses reçues, il a été conclu qu'un système utilisant des batteries Zebra de MES-DEA était la seule solution satisfaisante.

Un prototype fonctionnel a été construit et soumis à des essais complets. Aucune contrainte, flexion ou résonance inacceptable n'a été constatée dans la structure. La performance du véhicule était généralement conforme aux attentes.

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EXECUTIVE SUMMARY

The QuickSider™ is an aerodynamic, all-electric, composite monocoque urban delivery vehicle being developed by Unicell Ltd., Purolator Courier Ltd., and ArvinMeritor Inc., with the support of several other companies. The concept for the vehicle was first developed by Unicell in 2000 and refined through extensive studies of Purolator's operations carried out in 2003. Development of the prototype began in early 2004 with the assistance of the Transportation Development Centre (TDC) of Transport Canada. Preliminary design work was done throughout 2004, culminating in a full-scale mock-up built in early 2005. This was used to simulate typical route operations and validate the productivity gains made possible by the vehicle's unique features. It was also used to test and refine the design of the monocoque structure. Detailed engineering design was undertaken in 2005. The prototype was completed in the first half of 2006 and subjected to a series of compliance, engineering, and operational tests that will continue throughout 2007. The next phase in the overall project is the production of a small demonstration fleet in 2008 that will be placed in service by Purolator to prove the commercial viability of the vehicle. If successful, production could begin in 2009.

The specific objectives related to TDC's participation in the QuickSider™ project, set in 2004 were:

1. To complete the structural design of the composite monocoque low-floor body with a target of achieving a 36 percent weight reduction relative to comparable conventional aluminum and steel van bodies, and
2. To explore the electric drive options in order to confirm the feasibility of a zero emission vehicle (ZEV) range of 120 km and a grid-to-wheels energy efficiency of 75 percent as compared to the gasoline-to-wheels energy efficiency of 11 percent in Purolator's current vehicles.

The first objective was largely achieved in that the prototype structure has functioned well in track tests and is thoroughly engineered in the critical, highly stressed areas around the suspension attachment points, and with the projected weight reductions possible in a production vehicle, the weight of QuickSider™ body will be in line with the targeted 3500 lb.

In designing the prototype, it was decided to use a structure of welded stainless steel tube for the floor, major load bearing elements and wheel boxes. It was recognized that this would add considerable weight relative to what could be achieved in an all-composite structure; however, this allowed the prototype to be completed while research into an all-composite structure continued.

Another early decision was to build a mock-up of the vehicle that could be used to test both the structural design and the operational utility of the concept. The mock-up design evolved through three major computer-aided design (CAD) iterations. The third iteration was subjected to finite element analysis (FEA), which led to further strengthening at specific points in the structure where excess deflections were indicated. It should be noted that in this work, the issue was to ensure adequate strength at the critical points in the structure. The FEA was not used to attempt any weight reduction. The mock-up was built in accordance with the final CAD design and subjected to a series of load tests. These tests resulted in

greater deflections than the FEA predictions; however, it was decided that further structural analysis with the mock-up was not warranted. The operational tests with the mock-up validated earlier estimates of a 10 percent route productivity improvement. As a result, Purolator requested that the capacity of the prototype vehicle be increased. The decision was made to make the QuickSider™ the same overall length as the current curbside delivery vehicle, and to maximize the cubic capacity within this constraint.

While the work with the mock-up was being done, possible all-composite floor structures were investigated. Two alternatives emerged: one based on Martin Marietta's TRANSONITE composite panel material; and the other on a moulded structure using Webcor Technologies' TYCOR fibreglass reinforced foam core material. Test panels from these two materials, as well as a welded steel panel, were designed, manufactured and tested. The results indicate that a TRANSONITE structure would be lighter but slightly more expensive than a comparable steel structure. However, a TYCOR structure would probably be the lightest as well as the least expensive solution. The next stage of development will be to design, manufacture and test an all-composite floor incorporating the wheel boxes and other features of the QuickSider™.

While the prototype QuickSider™ body is only 3 percent lighter than the equivalent structure in a conventional truck, it appears that the structure can be optimized to achieve a 25 percent or greater reduction in weight compared to the conventional benchmark. The prototype vehicle was designed and made with a stainless steel and aluminum floor structure, as the high cost and technical uncertainty of an all-composite floor would entail excessive risk and development time for a prototype vehicle. Further research will be undertaken and could result in a lighter all-composite floor in production vehicles.

The second objective was also largely achieved. BET Services Inc. created a statement of requirements for the battery system for the prototype QuickSider™. This was distributed to several potential battery suppliers, only five of which responded. The decision was to order a BET Series B4Z battery system based on a set of four "Zebra" NaNiCl batteries manufactured by MES-DEA for the prototype. These are the only commercially available batteries that could meet our needs. However, the cooling, charging and management systems to support these high-voltage, high-temperature batteries add to the total weight of the battery system installed in the prototype. An alternative battery system that will meet our requirements is being developed by Electrovaya Inc. This promises to provide better power output and to be both lighter and less expensive. This battery will be tested in the next phase of development. If it proves suitable, it could be offered in production vehicles. Dynamometer tests have shown the ZEV range of the prototype to be greater than the targeted 120 km. The vehicle's overall energy efficiency is 50 percent, as compared to the conventional vehicle's 11 percent. With improvements to the battery system, drive train, regenerative braking and auxiliary systems, an overall energy efficiency of 75 percent is achievable in production vehicles.

Testing of the prototype will be completed during the balance of 2007. If the prototype meets its performance objectives and the business case shows the vehicle to be commercially viable, a small test fleet will be produced and placed into service with Purolator. If experience with the test fleet is satisfactory, full-scale production could be launched in 2009.

SOMMAIRE

Le QuickSider™ est un véhicule de livraison urbain tout électrique à carénage aérodynamique et à carrosserie monocoque en composite développé par Unicell Ltd., Purolator Courrier Ltée et ArvinMeritor Inc., avec l'appui de plusieurs autres entreprises. Le concept du véhicule a d'abord été développé par Unicell en 2000, puis peaufiné après un examen approfondi des opérations de Purolator, réalisé en 2003. Le développement du prototype, auquel a participé le Centre de développement des transports (CDT) de Transports Canada, a commencé au début de 2004. La conception préliminaire s'est poursuivie tout au long de 2004 et a débouché sur la construction, au début de 2005, d'une maquette grandeur réelle. Cette maquette a servi à simuler l'exploitation de la camionnette sur des circuits types et à valider les gains de productivité rendus possibles par les caractéristiques uniques du véhicule. Elle a aussi servi à tester et perfectionner le modèle de structure monocoque. Des études techniques détaillées ont été entreprises en 2005. Le prototype a été construit pendant la première moitié de 2006 et il a été soumis à des essais de conformité, des épreuves techniques et des essais opérationnels, qui doivent se poursuivre pendant toute l'année 2007. La prochaine phase du projet global consistera à produire, en 2008, quelques camions de démonstration, que Purolator intégrera à son parc pour confirmer la viabilité commerciale du véhicule. Si cet essai en service est concluant, la production de véhicules de série pourrait commencer en 2009.

Voici les objectifs précis de la participation du CDT au projet QuickSider™, tels qu'établis en 2004 :

1. mener à terme la conception structurale de la carrosserie monocoque en composite à plancher bas, en visant une réduction de poids de 36 p. 100 par rapport à la carrosserie des camionnettes classiques en aluminium et acier;
2. étudier les options en matière de propulsion électrique, afin de confirmer la faisabilité d'une autonomie de 120 km pour un véhicule à émission nulle (VÉN) et d'un rendement énergétique de 75 p. 100 (pourcentage de l'énergie électrique consommée effectivement transmise aux roues), comparativement au taux de 11 p. 100 de l'énergie tirée de l'essence effectivement transmise aux roues, dans les véhicules actuels de Purolator.

Le premier objectif a été largement atteint. En effet, la structure du prototype a affiché de bonnes performances lors d'essais sur circuit; des solutions techniques ont été mises au point pour les zones critiques sujettes à de fortes contraintes, autour des points d'attache de la suspension. Par ailleurs, grâce aux réductions de poids prévues pour un véhicule de série, la carrosserie du QuickSider™ aura un poids conforme à l'objectif fixé, soit 3500 lb.

Lors de la conception du prototype, il a été décidé de miser sur une structure de tubes en acier inoxydable soudés pour le plancher, les principaux éléments porteurs et les cages de roues. Certes, un tel choix allait ajouter un poids considérable au véhicule, par rapport à une structure tout-composite, mais il donnait la possibilité de terminer le prototype, pendant que se poursuivait la recherche sur une structure tout-composite.

Une autre décision prise d'entrée de jeu a été de construire une maquette pour pouvoir tester tant la conception structurale que l'utilité opérationnelle du concept. La maquette a évolué au fil de trois itérations de conception CAO (conception assistée par ordinateur). Le résultat de

la troisième itération a été soumis à une analyse par éléments finis (AEF), qui a conduit au renforcement de certains points de la structure, où des flexions excessives avaient été constatées. Il convient de noter que cette analyse visait à assurer une résistance adéquate aux points critiques de la structure, et non à en réduire le poids. La maquette a été construite conformément au modèle CAO final, et soumise à une série d'essais en charge. Ces essais ont révélé des flexions plus importantes que ne le laissait présager l'AEF; malgré cela, il a été décidé qu'il n'était pas nécessaire de poursuivre l'analyse. Les essais opérationnels à l'aide de la maquette ont validé les estimations faites antérieurement, soit une hausse de productivité de 10 p. 100 des opérations de messagerie. Purolator a donc demandé que la capacité de chargement du prototype soit augmentée. C'est alors qu'il a été décidé que le QuickSider™ aurait la même longueur hors-tout que la camionnette de livraison actuelle, et que l'on maximiserait sa capacité volumique dans les limites de cette contrainte.

Parallèlement aux travaux sur la maquette, des recherches étaient menées sur de possibles structures de plancher tout-composite. Deux options sont ressorties : la première faisant appel au panneau composite TRANSONITE de Martin Marietta, l'autre, à une structure moulée utilisant, comme âme, un panneau de mousse renforcée de fibre de verre TYCOR de Webcor Technologies. Des panneaux d'essai constitués respectivement de ces deux matériaux, de même qu'un panneau en acier soudé, ont été conçus, fabriqués et testés. Les résultats on indiqué que la structure TRANSONITE serait plus légère, mais un peu plus chère qu'une structure en acier comparable. Toutefois, une structure TYCOR serait probablement la solution à la fois la plus légère et la plus économique. La prochaine phase de développement consistera à concevoir, fabriquer et mettre à l'essai un plancher tout-composite intégrant les cages de roues et les autres caractéristiques du QuickSider™.

Le prototype de la carrosserie du QuickSider™ représente une réduction de poids de seulement 3 p. 100 par rapport à la structure équivalente d'une camionnette classique. Il semble toutefois possible de perfectionner la structure pour atteindre une réduction de poids de 25 p. 100, voire plus, comparativement à la camionnette classique. Pour la conception et la construction du prototype du véhicule, on a utilisé une structure de plancher en acier inoxydable, car le coût élevé et les difficultés techniques associés à un plancher tout composite auraient entraîné un risque et des retards indus dans le développement du prototype. Il est possible que d'autres recherches, d'ailleurs projetées, mènent à doter les véhicules de série d'un plancher tout-composite léger.

Le deuxième objectif a lui aussi été largement atteint. BET Services Inc. a établi un énoncé des besoins pour les batteries du prototype du QuickSider™. Cet énoncé a été transmis à plusieurs fournisseurs de batterie potentiels, dont seulement cinq ont répondu. Il a été décidé de commander, pour le prototype, un système de batteries Série B4Z de BET, soit un ensemble de quatre batteries « Zebra » au NaNiCl fabriquées par MES-DEA. Ce sont les seules batteries offertes sur le marché qui pouvaient répondre à nos besoins. Toutefois, les systèmes de refroidissement, de recharge et de gestion qui accompagnent ces batteries haute tension et haute température ajoutent au poids de celles-ci, et du prototype. Electrovaya Inc. est à développer une nouvelle batterie qui répondra à nos exigences. Cette batterie promet d'offrir une plus grande puissance, tout en étant plus légère et moins coûteuse. Elle sera mise à l'essai au cours de la prochaine phase de développement. Si ces essais sont concluants, cette batterie pourrait équiper les véhicules de série. Des essais sur dynamomètre ont démontré que l'autonomie du prototype de VÉN était supérieure aux 120 km visés. Le rendement énergétique global du véhicule est de 50 p. 100, par rapport aux 11 p. 100 des véhicules classiques. Moyennant des améliorations aux batteries, au groupe motopropulseur, au freinage par récupération et aux systèmes auxiliaires, un rendement énergétique global de 75 p. 100 pourrait être atteint dans les véhicules de série.

L'essai du prototype aura lieu en 2007. Si les objectifs de performance sont atteints et que l'analyse de rentabilisation montre que le véhicule est commercialement viable, quelques véhicules seront construits et mis en service chez Purolator. Si l'expérience de ce parc d'essai s'avère satisfaisante, la construction de véhicules de série pourrait débuter en 2009.

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GLOSSARY OF ACRONYMS

BEV	Battery Electric Vehicle
BMI	Battery Management Interface
CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics
CW&N	Customer Wants and Needs
DDOD	Daily Depth of Discharge
FEA	Finite Element Analysis
g	force of gravity
GVWR	Gross Vehicle Weight Rating
ICE	Internal Combustion Engine
MBS	Multiple Battery Server
RFP	Request for Proposals
SOR	Statement of Requirements
TDC	Transportation Development Centre
ULFA	Ultra Low Floor Axle
ZEV	Zero Emission Vehicle
3D	Three Dimensional

1. Introduction

Courier pick-ups from and deliveries to urban locations is one of the fastest growing surface transportation applications. Typically, courier vehicles operating on urban routes cover relatively short distances, but can make more than 100 stops during each business day. After spending eight or more hours on a route, these vehicles are parked overnight while they are serviced and loaded for the next day's deliveries.

The vehicle most commonly used on urban courier routes is referred to as a step van or curbside delivery van. There are over 200,000 step vans in use in North America. Most are gasoline powered and average 37,000 km annually at about 1.4 km/L of fuel for a total consumption of over 5 billion litres. Their conversion efficiency from gasoline to energy at the wheels averages 11 percent. Courier companies use these vehicles extensively. Over 50 percent of courier routes are in urban settings where they average less than 100 km per day – an ideal setting for an electric vehicle that can achieve higher energy efficiencies and eliminate on-street emissions.

Step van design has changed little over the past 40 years. These vans are made up of an aluminum body built onto a conventional gasoline-powered truck chassis. Their long wheelbase, which is necessary to provide adequate volume, leads to a wide turning radius, and their overall height and shape results in high aerodynamic drag and poor handling characteristics. In addition, their high floor, positioned above the drive shaft and differential, requires couriers to take two uneven steps up or down as they enter or leave the van. This is the major cause of couriers' on-the-job accidents and has a debilitating effect on couriers' knees and hips over the course of their careers. The high floor height also adds to the time required for each pick-up or delivery, reducing the efficiency of operations. Corrosion in the aluminum and steel structure limits their useful life to about 10 years. Although they have many operational disadvantages, their capital cost is relatively low.

Unicell Ltd., which builds some 3000 composite truck bodies annually for the light- and medium-duty commercial truck market, believes there is a better solution for urban courier operations. It has developed a bold, new, socially responsible and more environmentally sustainable design for an efficient urban delivery vehicle called the QuickSider™.

The QuickSider™ has been conceived as a lightweight aerodynamic composite monocoque all-electric urban delivery vehicle. Its electric drive eliminates on-street emissions from the vehicle and reduces full-cycle greenhouse gases by more than 80 percent (based on the Ontario electrical grid's off-peak performance). Its on-board battery charging system draws off-peak power from the grid while the vehicle is parked overnight. Its lightweight aerodynamic composite monocoque body minimizes its energy and power requirements, and has a useful life estimated at 20 years. It uses independent electric drives on each rear wheel to achieve a low floor, and air suspensions to allow the rear to lower to ground level so that cargo can be rolled in or out. These and other features provide for greatly improved safety, energy efficiency, route productivity, durability, maintainability and service life. Although its cost will be greater, its operational advantages will make it commercially viable in competition with conventional step vans.

Unicell developed the QuickSider™ concept in 2000 and refined it through a joint study carried out by Unicell Ltd. and Purolator Courier Ltd. in 2003. Unicell's staff studied Purolator's operations on routes and in terminals in order to gain an understanding of how vehicle features could contribute to improved productivity and safety. Purolator couriers, operations managers and industrial engineers reviewed the resulting design concept to confirm the expected benefits.

Initial estimates resulted in a viable business case; however, Unicell realized that the vehicle would not be acceptable to a broad market unless key components were provided by established suppliers. ArvinMeritor was invited to develop and supply the drive train and suspension components for the vehicle and responded enthusiastically. Development of the prototype began in early 2004 with the assistance of the Transportation Development Centre (TDC) of Transport Canada. Preliminary design work was done throughout 2004, culminating in a full-scale mock-up built in early 2005. This was used to simulate typical route operations and validate the productivity gains made possible by the vehicle's unique features. It was also used to test and refine the design of the monocoque structure. Detailed engineering design was undertaken in 2005. The prototype was completed in the first half of 2006 and subjected to a series of compliance and engineering tests. Testing was interrupted by the premature failure of two batteries. Prototype testing resumed in March 2007 and will continue throughout the balance of the year to validate the design and identify opportunities for improvement, both to the vehicle and its manufacturing process. The next phase in the overall project will be the production of a small demonstration fleet in 2008. If the fleet demonstration is successful, production could begin in 2009.

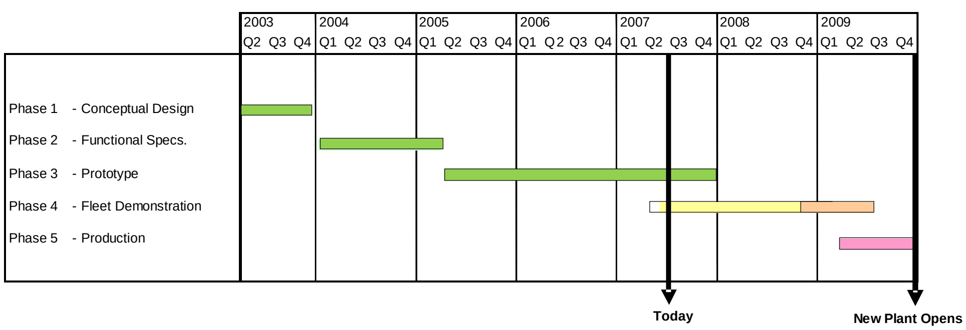

Figure 1: QuickSider™ Project Timeline

TDC has provided vital support to the project over the past three years in two technically challenging areas of development. The first of these was the development of the structural design, including the manufacture and testing of the mock-up as the basis for the prototype vehicle, and research into the design of a composite floor structure that, if proven feasible, will further reduce the weight of the vehicle and allow the incorporation of additional features. The second was the development of a battery system specification for the vehicle. In addition, TDC's continuing advice and support throughout the project has been invaluable.

This report documents the overall QuickSider™ development to date and, in particular, the work done with the support of TDC.

Several organizations in addition to those already mentioned have played an important role in the QuickSider™ development. A full list of the organizations participating in the QuickSider™ project is shown in Table 1.

Table 1: Participating Organizations

Organization	Role
Unicell Ltd.	Lead organization, vehicle developer and integrator
Purolator Courier Ltd.	Development partner and demonstration host
ArvinMeritor Inc.	Drive train and suspension developer
Electrovaya Inc.	LiPo battery supplier
Southwestern Energy Inc.	Battery lease supplier
Transportation Development Centre	Technical advice and financial support
BET Services, Inc.	Zebra battery testing and "balance of battery system" developer
PMG Technologies Inc.	Vehicle track testing
Bodycote Material Testing Canada Inc.	Vehicle structural analysis and testing
Bélanger.com Inc.	Composite structure design review

The work of Bélanger.com and BET, as described in this report, has been supported by the contract with TDC.

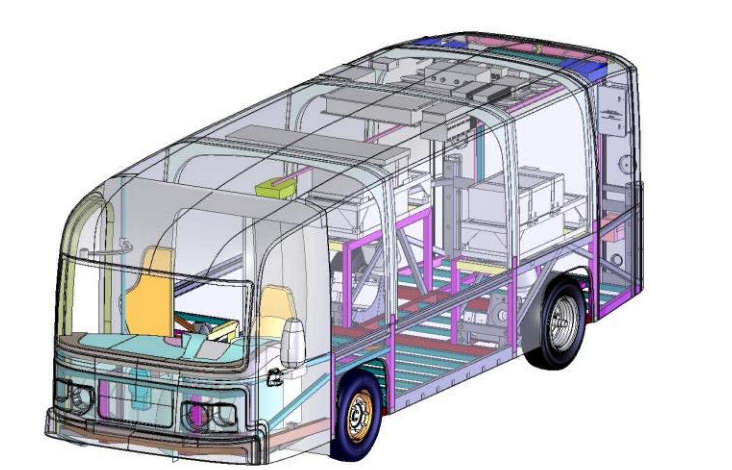

Figure 2: QuickSider™ Prototype Design

2. Objective

Unicell's ultimate objective is to develop a commercially viable lightweight composite monocoque electric urban delivery vehicle closely matched to the operating requirements of courier companies. The vehicle, tentatively named the QuickSider, is designed to meet Purolator Courier Limited's published specifications for payload, speed, acceleration and handling. The vehicle is expected to cost more than its conventional equivalent; however, it will offer substantially improved route productivity and safety. In addition, the vehicle will produce zero on-street emissions and reduce greenhouse gas emissions by 87 percent.

The specific objectives related to TDC's participation in the QuickSider™ project are:

1. To complete the structural design of the composite monocoque low-floor body with a target of achieving a 36 percent weight reduction relative to comparable conventional aluminum and steel van bodies, and
2. To explore the electric drive options in order to confirm the feasibility of a Zero Emissions Vehicle (ZEV) range of 120 km and a grid-to-wheels energy efficiency of 75 percent as compared to the gasoline-to-wheels energy efficiency of 11 percent in Purolator's current vehicles.

3. Scope

The project was structured to pursue the two specific objectives defined above in parallel. As suggested by TDC, the work was divided into two parts – the body structural design work and the electric drive assessment work – with this, the final report, presenting the results of both parts.

Shortly after the TDC participation was defined, Unicell secured the participation of ArvinMeritor of Troy, Michigan, who agreed to undertake most of the power train and suspension development work. Consequently, TDC's support effort shifted toward the design and installation of the battery energy storage and recharging system.

Unicell conducted most of structural design for the prototype internally, with some of the specialized finite element modeling, analysis and testing contracted to Bodycote. Early in the design of the QuickSider™ prototype, it was decided to manufacture the floor and wheel boxes as a stainless steel structure covered with sheet aluminum. This decision was based on the relative certainty of the design parameters, given Unicell's extensive experience with this type of structure. Although it was believed that there could be several advantages to an all-composite understructure, there were too many uncertainties in such a design to warrant its use in the prototype. Further research is needed to establish whether this approach will be practical for production vehicles. The first step in this research became the subject of a contract awarded to Bélanger.com Inc. to provide external expert advice on the vehicle's composite body development, and to develop an alternate lightweight composite floor design. The development of the battery system specification, testing and installation has been completed via a contract awarded to BET. The TDC contract, as amended, supported the work of Bélanger.com Inc. and BET.

4. Background

The first phase in the development of an improved urban delivery truck was undertaken by Unicell prior to April 2003, at which time Purolator agreed to participate in a study of urban delivery requirements with the objective of developing a vehicle specifically tailored to its operational needs. The functional specifications for a new vehicle were created by studying Purolator's route operations and related terminal and maintenance activities, and using the resulting information to define desirable vehicle features and capabilities. This work was done during 2003 and early 2004. Some of the important conclusions of this work were that a new vehicle should:

- meet or exceed the payload, volume and performance capabilities of the16 ft. curbside vans used by Purolator (essentially, these are made up of aluminum bodies mounted on 14,050 lb. gross vehicle weight rating (GVWR) Ford truck chassis),
- have a continuous, uniform low floor requiring only a single step to enter or exit,
- have automatically actuated doors in the right side, rear and cargo bulkhead,
- have a kneeling suspension allowing roll-on/roll-off loading and unloading,
- have an ergonomically sound driver's station, including an efficient "office",
- be powered by independent all-electric drives on each rear wheel, and
- have a range of at least 60 km in winter operating conditions.

The independent rear wheel drives are necessary to achieve the low floor, which is the key to improved productivity and safety. With the all-electric drives, the vehicle can use off-peak grid electricity to recharge the batteries, completely eliminating on-street emissions and reducing greenhouse gases by 87 percent (based on the Ontario grid).

Analysis by Unicell indicated that the above features and capabilities would allow courier productivity to be improved by about 10 percent, substantially reduce the risk of on-the-job accidents, reduce cargo damage and improve security. This analysis was reviewed and confirmed by Purolator's industrial engineering staff.

The preliminary engineering design work was done in 2004 and culminated in the construction of a mock-up, which was completed in early 2005. This was used by Purolator's couriers to simulate route operations and validate the expected productivity and safety improvements made possible by the vehicle's unique features.

One important outcome of this work was the decision to increase the cubic capacity and payload of the vehicle. The original requirement was for a vehicle with the same capacity as that of the conventional 16 ft. van, which led to a design whose overall length was over a foot shorter than that of the conventional 16 ft. van. Simulated operations with the mock-up proved that route productivity would be improved and that new services such as pallet deliveries could be accommodated. As a result, the specification was changed so that the QuickSider™ would match the overall length of the conventional 16 ft. van. Because of its set-back front wheels, the QuickSider™ will still have a shorter turning diameter and improved handling. The result is an increase in cubic capacity to match that of the 19 ft. conventional van, and a corresponding increase in the payload capacity.

During this same period, the specifications for the electric storage system were developed by Unicell and its contractor, BET. This work included the preparation of the Zebra batteries and their supporting systems for installation in the prototype, and a Request For Proposal (RFP) suitable for release to other potential battery suppliers. This document was supplied to Electrovaya, who will produce a Lithium Polymer battery for testing in the QuickSider™ prototype.

Also during this period, all of the ancillary systems required by the vehicle were defined, suitable suppliers identified, moulds made for the fibreglass components, and prototype parts produced. Working in parallel with Unicell, ArvinMeritor developed the electric drive, suspension and steering system for the vehicle. This effort culminated with the assembly of the prototype vehicle, which was completed on April 19, 2006. The prototype has been subjected to the initial testing in ArvinMeritor's facilities in Troy, Michigan, and Environment Canada's facilities in Ottawa, Ontario. Compliance and performance testing by PMG at the Transport Canada facility in Blainville, Quebec, began in the fall of 2006 and was completed in the spring of 2007. Following some modifications and upgrades, Purolator will conduct operational testing and Bodycote will perform accelerated life-cycle testing.

Assuming the prototype testing proves the design, a batch of 10 pre-production vehicles will be assembled and placed into service with Purolator in late 2008 as a demonstration of the QuickSider's performance and operational capabilities. If the fleet test demonstrates the commercial advantages of the QuickSider™ and a substantial order is received, regular production could begin as early as mid-2009.

5. Business Case

From the inception of the project, the primary criterion to pass each milestone has been that the QuickSider™ would perform as well or better than competitive vehicles and could be sold profitably at a competitive price. For comparative purposes, the Utilimaster 16 ft. curbside van was taken to be the competition. The initial analysis led to the conclusion that once established in production, the QuickSider™ would probably cost 50 percent more than a conventional vehicle, but that its improved productivity and safety benefits would result in an acceptable payback on the increased investment of approximately 3.5 years. This analysis placed no economic value on the QuickSider's elimination of on-street emissions or the 87 percent reduction in greenhouse gas production, which are of great social value. This conclusion regarding the economic viability of the QuickSider™ has been confirmed at each step of the project to date, and will continue to be examined as more precise information is developed. The data supporting this conclusion are confidential until the vehicle is released to the market.

In addition to technical and operational requirements, the probability of commercial success will be the primary basis for the decision to proceed at each project milestone.

6. Development of the Lightweight Body

6.1. Introduction

The overall purpose of the work reported on below was to complete the structural design of the prototype QuickSider™ electric delivery truck. The QuickSider's basic architecture is different than that of a conventional delivery truck in several ways:

1) Whereas the primary structural element of a conventional truck is the chassis frame, to which the suspensions and the structurally redundant body are attached, the QuickSider™ has no such frame; it is a "monocoque" or "unibody" design. The QuickSider's body, therefore, is the primary structural element. The body must be designed to handle all the loads imposed on the vehicle in operation.
2) Whereas a conventional delivery truck has a floor height of more than 30 in., the QuickSider's floor height is 14 in. The floor surface is an uninterrupted plane, with no "humps" in it, from the side door, which is forward of the front wheels, to the rear door at the very back of the vehicle. This means that all the structures to support the vehicle's floor and its suspensions must fit between the 14 in. high surface of the floor and the ground. In operation, the minimum acceptable ground clearance is different in different places in the vehicle. It is 12 in. midway between the front and rear wheels and 9 in. in the wheel areas. The maximum depth of the structure in the floor of the vehicle, therefore, is 2 in. midway between the front and rear wheels and 5 in. in the wheel areas.
3) Whereas a conventional delivery truck stays level at all times, with its floor surface more than 30 in. off the ground, the QuickSider™ kneels fully to the ground at the back, enabling carts to be rolled in and out of the cargo area. In order to facilitate the movement of the carts, the floor structure must be as thin as practical at the back of the vehicle.
4) Whereas a conventional delivery truck has a one-piece rear axle, the QuickSider™ has independent rear suspensions that are electrically powered and kneel. The transverse bending moments from the rear wheels that are carried by the rear axle in a conventional truck must be carried by the body structure of the QuickSider™.

These fundamental differences in the QuickSider's architecture mean that little of the knowledge of the structural requirements and design practices of conventional trucks is transferable to the QuickSider™. It was therefore decided that a broad structural design program be undertaken for the QuickSider, making extensive use of Finite Element Analysis (FEA). TDC undertook to support some of this work.

This report follows the design process in chronological order, beginning with the design, FEA and construction of a full scale mock-up, then the design and FEA of a detailed first generation Computer-Aided Design (CAD) model of the complete truck, and finally the design and FEA of the CAD model from which the prototype truck was actually built.

6.2. Body Weight Reduction Target vs. Current Technology

Purolator's current standard vehicle for this application consists of a Utilimaster step van body mounted on a Ford E450 chassis. The fact that the body and the chassis in this configuration are each independently capable of carrying most of the structural loads of the whole vehicle creates an opportunity for weight reduction with the monocoque approach by eliminating most of the weight of the chassis frame. The initial weight reduction target for the QuickSider™ monocoque body was derived as follows:

Current curb weight of step van on Ford E450 Chassis	8,000 lb.
Less engine, transmission, drive train, suspension & wheels	2,500 lb.
Difference = combined weight of body and chassis frame	5,500 lb.
Target weight of Unicell monocoque body	3,500 lb.
Absolute weight reduction if target achieved	2,000 lb.
Percentage weight reduction if target achieved	36 percent

6.3. Design and FEA of the Mock-up

The purpose of the mock-up was to enable full-scale evaluation of the vehicle concept in terms of layout, simulated operations and basic structure. The mock-up was constructed of readily available parts and materials. The fibreglass parts used in the mock-up were made from Unicell's truck body moulds.

6.3.1. Initial Design of the Mock-up

The basic configuration and dimensions of the mock-up were based on the concept vehicle design that resulted from the design study that Unicell did with Purolator from April to November of 2003. Figure 3 is a computer rendering of the concept vehicle.

Figure 3: November 2003 Vehicle Concept

The key dimensions of the mock-up are given in Table 2.

Table 2: Key Dimensions of the Mock-up

Dimension	Chosen Value(s)	Reason(s)
Length	297 in.	7 in. shorter than current 16 ft. vehicle
Width	96 in.	Same as current vehicle
Inside Height	81.5 in.	Same as current vehicle
Floor surface height	14 in.	As low as practical while achieving target angles of approach, departure and breakover.
Departure angle	9.5 degrees	Same as current vehicle
Front and rear wheelbox sizes	Various, from ArvinMeritor	To accommodate suspensions to be supplied by ArvinMeritor

6.3.2. First Iteration of the 3D CAD Model

An initial 3D model of the QuickSider™ mock-up was created in SolidWorks as a fully detailed assembly, with a composite body made of ¼ in. thick fibreglass and a floor made of stainless steel tubing. In addition, front & rear bulkheads were included, as well as longitudinal shelving for proper loading simulation, simplified front and rear suspensions for support definition, and both side and rear door openings in the main shell defined as a weakening features. Figure 4 shows the initial CAD model of the mock-up.

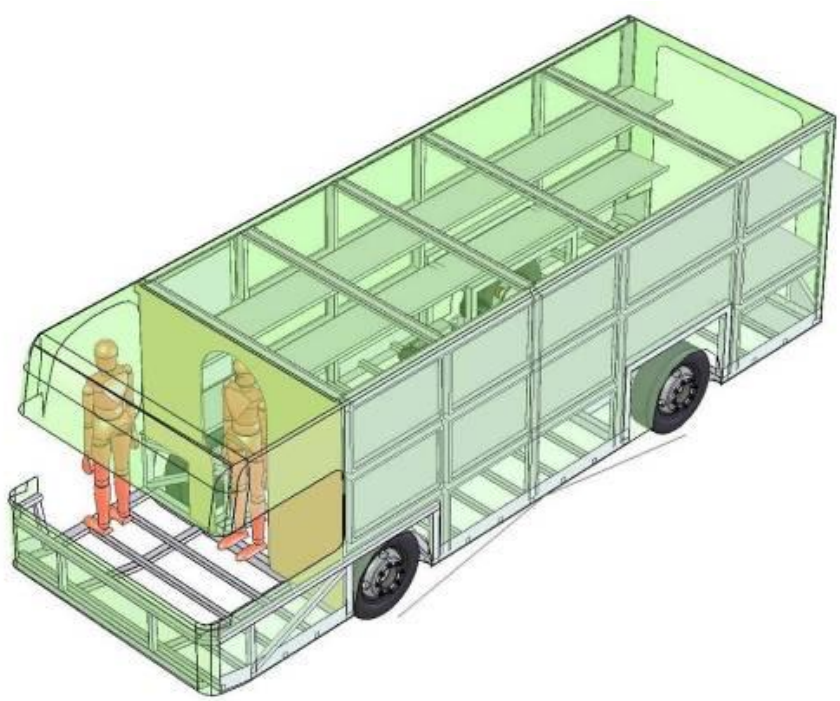

Figure 4: First Iteration CAD Model of the Mock-up

6.3.3. Second Iteration of 3D CAD Model Based on Team Review and Structural Analysis

Before doing FEA or physically building the mock-up, the design team reviewed the initial three-dimensional (3D) model developed in SolidWorks. As a result of this review, which included a structural analysis of key components, the initial design was changed somewhat and a second-iteration SolidWorks model developed. For example, the cross-member spacing was made tighter because beam calculations revealed that the original spacing would result in too much deflection under load.

6.3.4. Third Iteration of 3D CAD Model Based on FEA

The second-iteration SolidWorks model was imported into ProEngineer/Wildfire software for additional design refinements and optimization. Once all structurally important details were designed a simplified FEA model was created for a linear stress analyses. The simplified representation of the vehicle was created using a combination of shell and beam elements to model the structural components. In this case, shell elements were used to define the main body, front & rear bulkheads, floor panels and longitudinal shelving. The beams were used to define floor and wheel-boxes, shelving supports, side and rear door frames and driver's peripheral encasement. The front and rear suspension were also represented by beam elements.

Thus defined, the simplified CAD model was transferred to ProMechanica (a module of ProEngineer) where a finite element mesh was automatically generated.

Initially, two linear static load cases were evaluated:

1. a four-wheel support case, and
2. a three-wheel support case in which the front right-hand side axle was unsupported.

The following loads and boundary conditions were used:

- Loads – all were evenly distributed over the corresponding region of the model;
  - 1000 lb. per shelf (4 shelves for a total of 4000 lb.),
  - 4500 lb. on floor panels (20,016 N)
- Restraints – proper degrees of freedom and moment releases were applied to each attachment point:
  - front independent suspension used five mount points per side
  - rear trailing arms used three mount points per side

The initial analysis revealed that although the stresses and deflections in the fibreglass body shell were predicted to be well within acceptable limits, the shelves and parts of the steel under-structure were predicted to exceed either their stress limit or their deflection limit, or both.

Therefore, several design iterations of the shelf and under-structure were done to improve their structural performance with respect to the given load cases. Most effort was focused on the shelving and the connection between the shelves and body shell. Figure 5 shows the results of one of the shelf design iterations.

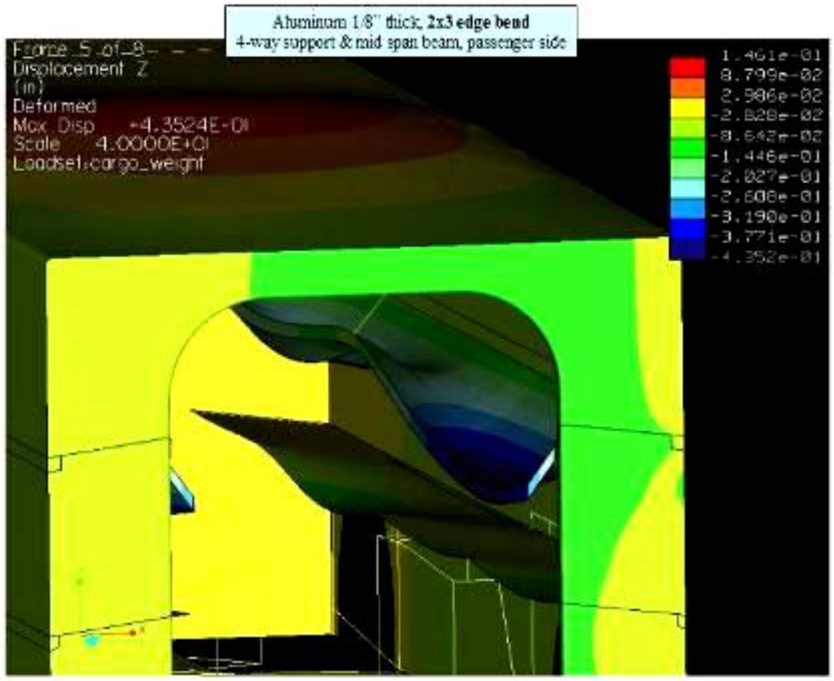

Figure 5: Shelf Design FEA Results
(Vertical deflections are magnified by a factor of 40)

In anticipation of the physical tests of the mock-up (see section 6.3.6), several analyses were run for a static load of 11,500 lb. of water distributed on the floor to simulate the vehicle loaded to its intended GVWR of 16,5000 lb. As a result of this work, a third-iteration 3D CAD model was developed.

6.3.5. Physical Mock-up

The physical mock-up was then built according to the third-iteration 3D model, including mocked-up kneeling suspensions, front and rear, and automatically actuated side and rear doors.

Figure 6: Views of the Mock-up

6.3.6. Mock-up Evaluation by Purolator

Once the mock-up was complete, it was first shown to Purolator's National Fleet Director at Unicell's facility for feedback. As this was positive, the mock-up was then shipped to one of Purolator's facilities for further evaluation by drivers, managers and engineers.

As part of the evaluation, Unicell worked with Purolator's industrial engineering staff to perform time-and-motion studies of various simulated pick-up and delivery operations using the mock-up and one of Purolator's current trucks. Purolator and Unicell then did a joint analysis of these studies and concluded that the expected productivity improvement created by the QuickSider™ on a typical urban route would be approximately 10 percent.

6.3.7. Deflection Tests of Mock-up Structure

When the mock-up returned to Unicell's facility, some basic structural tests were done to it to determine the correlation between the structural behaviour of the as-built structure and that of the FEA model.

Two basic structural tests were performed on the mock-up in order to correlate the structural response predicted by the FEA model to the actual physical behaviour of the as-built mock-up. In each test, the mock-up was loaded by filling the cargo area with 11,500 lb. of water as shown in Figure 7. This brought the mock-up weight up to the intended fully loaded weight of the vehicle.

Figure 7: Mock-up with Water Load

In the first test, all four wheel locations were supported, while in the second test the supports were removed from the front right wheel, leaving just three support points. Deflections were measured on the left-hand side of the vehicle, midway between the front and rear axles, and on the right-hand side of the vehicle at the rear edge of the side door opening. Table 3 shows the results of these tests and compares them to those predicted by the FEA model.

Table 3: Predicted and Actual Mock-up Deflections

Support Condition	Measurement Point	Actual Deflection	FEA Predicted Deflection @ E= 1M
Four points	Left side	0.098 in.	0.031 in.
Four points	Right side	0.117 in.	0.029 in.
Three points	Right side	0.162 in.	0.131 in.

This simple correlation study shows a significant difference between the predicted results and the test results. The model and the physical prototype were examined in some detail, and it was determined that there were many potential sources for this variance, for example:

- The FEA model was potentially over-constrained at the support points,
- The material properties used were generic properties, which might not be accurate for the as-built mock-up, or
- The FEA models of the bonded/bolted/riveted connections were idealized as "perfect" joints, which might not be representative of the actual connections.

It was decided that it was not worth the time and cost to fully understand the source of the variances between the structural behaviour the mock-up and that of the FEA model, and that it would be more cost effective to address the identified potential sources of such variances in future iterations of the design/analyze/test cycle.

6.4. Initial Design and FEA of the QuickSider™ CAD Model

The mock-up work indicated that the basic architecture of the QuickSider™ concept could offer large operational benefits for the customer, and that the structural design approach was satisfactory. The next step in developing a fully detailed truck design was to create a CAD model of a complete truck and to analyze it with FEA.

6.4.1. Joint Development with Bodycote of the Initial CAD Model of the QuickSider™ Preliminary Design

Bodycote Materials Testing Canada, Inc. has extensive expertise in the structural evaluation and design life testing of urban transit buses, having done such work for several major Canadian and U.S. bus manufacturers over a number of years. This expertise is relevant to the QuickSider™ since modem transit buses have a similar basic structural design to that of the QuickSider, and, just as importantly, they operate under very similar service conditions. Buses are typically low-floor vehicles, with the driver and front side door ahead of the front wheels. Most buses use welded stainless steel, mostly HSS tubing, in their under-structure and their suspension attachment structures. They also use a combination of steel tubes and shear panels as superstructures to carry the body loads. In terms of operation, urban transit buses and urban delivery vehicles operate on similar road conditions, with similar stop-and-go type driving.

Bodycote has developed a 13 step Transit Bus Design Life Qualification Methodology for qualifying the service life of vehicles. Finite element modeling is the third step in that methodology. As Unicell expects to engage Bodycote for later work in the vehicle qualification process, such as strain-gauged road tests and “shaker” tests, it elected to first engage Bodycote to do an FEA of the QuickSider™ concept. To do this, it was necessary to create a CAD model that was more representative of a real-world truck than the mock-up model.

Unicell worked with Bodycote to create a full model for FEA. The CAD for the new model is shown in Figure 8. It included geometry and masses of the following:

- an updated body design that had 5 in. more inside height than the mock-up, based on Purolator’s input, and was shaped more closely to that of a practical truck
- a floor structure that was detailed to accept the Arvin-Meritor suspension components
- the suspension components themselves
- main Zebra batteries
- electrical and mechanical components
- glass windshield
- payload

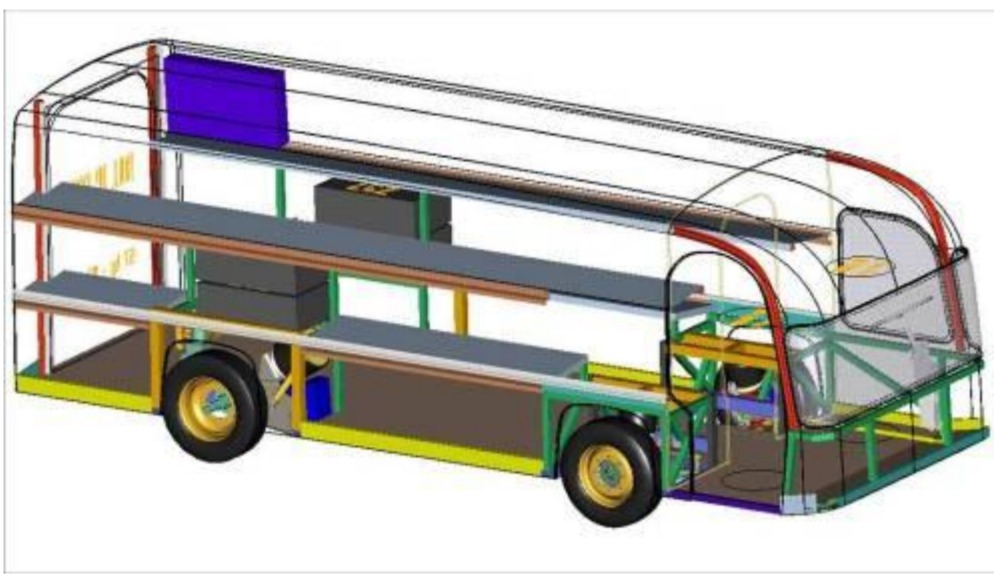

Figure 8: Initial CAD Model of the QuickSider™ Preliminary Design

6.4.2. FEA of Initial CAD Model of a Complete Truck by Bodycote

Once the CAD model of the preliminary design was complete, Bodycote created an FE model based on it, which is shown in Figure 9.

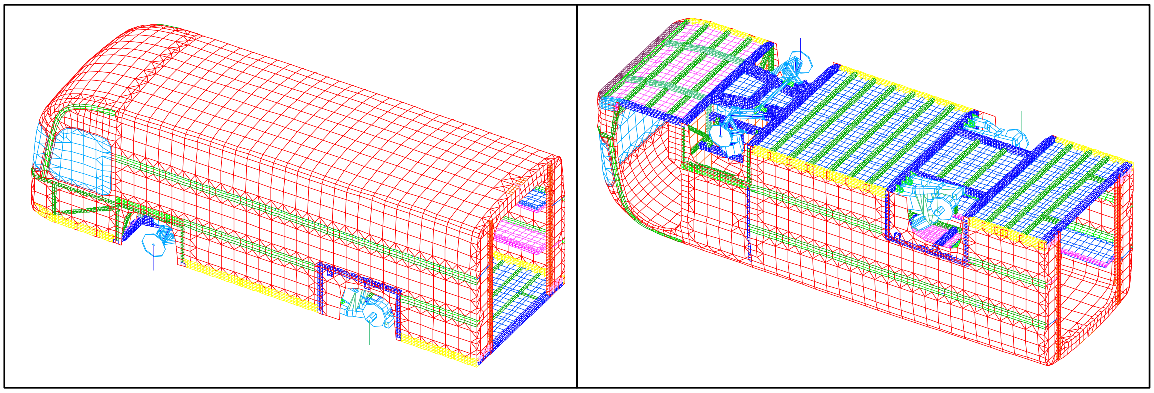

Figure 9: Top and Bottom Views of the Bodycote FEA Model

Bodycote then subjected the FE model to four load cases:

1. 1 g Vertical Acceleration (Heave)
2. 1 g Fore/Aft Acceleration (Braking)
3. 1 g Lateral Acceleration (Cornering)
4. 1 g Vertical Acceleration with "Altoona" twist

The "Altoona" twist of case 4 is created by lifting the front curbside and rear roadside tire patches by 6 in.

From its experience with transit buses, Bodycote has developed "design stress criteria" which are used to evaluate vehicle structures using finite element methods. Bodycote has learned that if the predicted stresses in the vehicle analyses are below the criteria stresses for a few given load cases, then the vehicle structure should survive for its design life under heavy-duty urban use. The criteria applied to the QuickSider™ FEA results are shown in Table 4.

Table 4: Bodycote Design Stress Criteria

Load	Design Stress Criterion (psi)
1 g Vertical	10,000
1g Fore/Aft	16,500
1g lateral	35,500

Note that the design stresses only apply to the stainless steel structures and not to the composites. Most of the predicted stresses from the analysis of the four load cases were well below these criteria. However, as shown in Figures 10 and 11, there were several areas in the structure where the stresses exceeded the design stress criteria in at least one of the load cases.

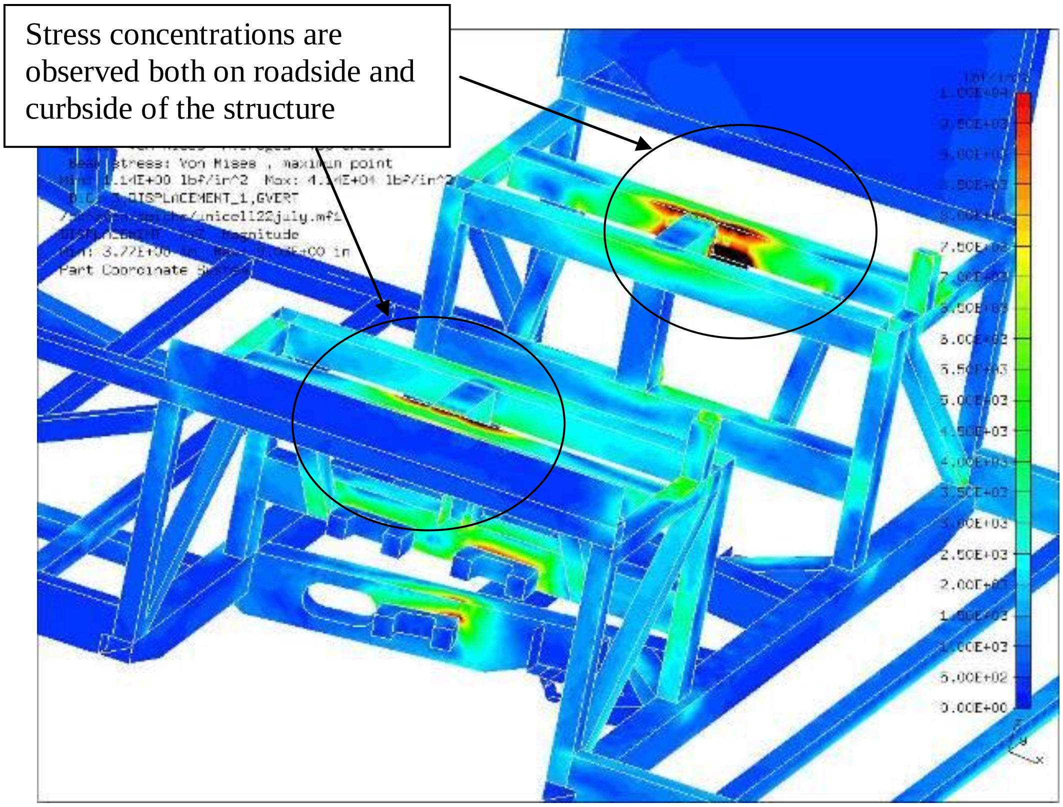

Figure 10: Bodycote FEA Results, Front Suspension Structure, Loaded, 1g Vertical

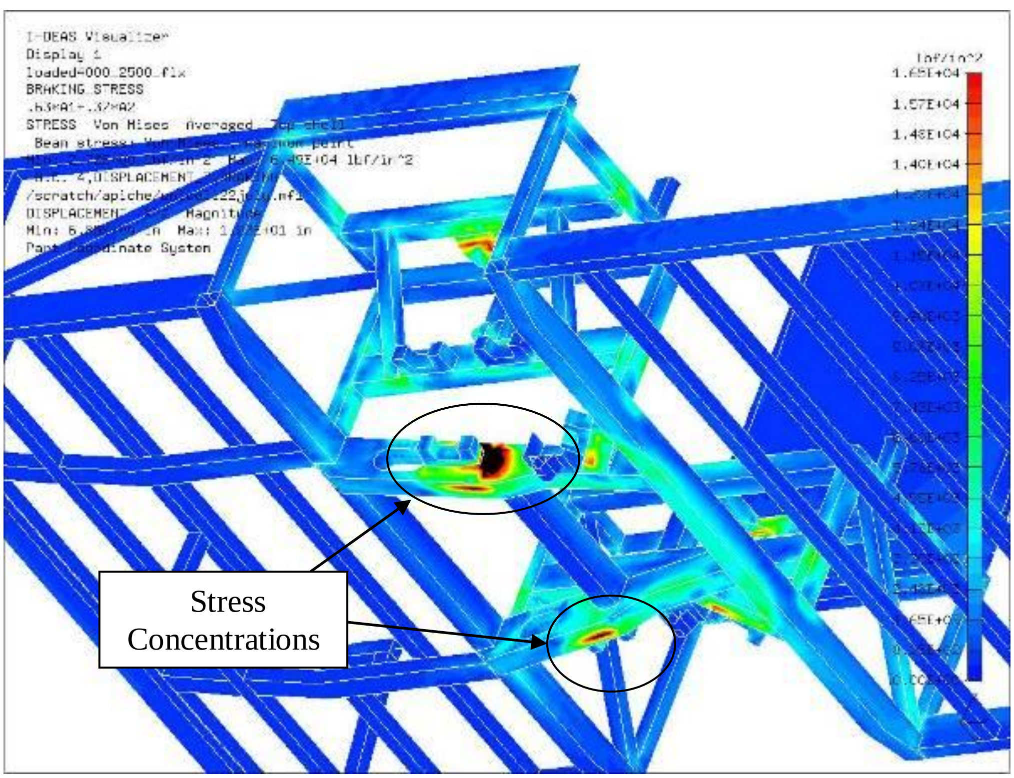

Figure 11: Bodycote FEA Results, Front Suspension Structure, Loaded, 1g Braking

Bodycote's final report recommended that there be "structural upgrades with larger tubes/gussets" in the following four locations:

1. Front upper suspension arm connections and support beams
2. Front lower suspension arm connections and support beams
3. Front airbag support beams
4. Load carrying rack support beams

6.4.3. Modal Analysis

In addition to stress analysis, Bodycote performed a modal analysis of the vehicle, examining the natural frequencies of the vehicle structure and suspension. This was done to ensure that there were no obvious couplings between the suspension and structural modes. The first 15 modes were calculated and reviewed by Bodycote.

The vehicle finite element model used for the linear static analysis was also used for this simulation. The wheel contact patches were restrained, simulating a "fixed" boundary condition where the vehicle is in contact with the ground plane.

Bodycote's final report summarized the results of the modal analysis as follows:

> "A key design requirement is to ensure that the possibility of stress (strain) amplification due to the coupling of the 1st Vertical Bending and the 1st Torsion modes with suspension "hop" and "tramp" modes would not occur. In this context, it is observed that there is no foreseeable coupling of suspension and body principal modes. Accordingly, it is likely that the design criteria are very conservative and leave open the possibility of further structural optimization after an initial road operating test."

6.4.4. Bodycote FEA – Conclusion

Bodycote's work indicated that there were some localized high stress regions in the vehicle structure, particularly around the suspension attachments. It was recommended that these areas be reinforced prior to performing a road-operating test. Generally, however, the analysis indicated that the vehicle structure as a whole, both the fibreglass body and the stainless steel floor structure, was quite lightly stressed, and could be made lighter.

Once the analysis was complete, Bodycote reported its results verbally to the Unicell design team in a joint team meeting. This was followed by a formal written report. Bodycote's FE model was then released to Unicell. Unicell's analyst performed additional FEA studies on the QuickSider™ design as it evolved, as reported in Section 6.5.

6.5. Design and FEA of the Prototype

The prototype incorporated the knowledge gained from Bodycote's FEA work as well as knowledge gained from other work that was done during the same period on operational productivity, drive train component layout, aerodynamic drag and overall vehicle packaging.

6.5.1. Design of Prototype Body Dimensions and Shape

Two areas were addressed to define the final body design: the cargo capacity relative to the current vehicle, and aerodynamic drag.

Time and motion studies done with the mock-up with Purolator indicated that the QuickSider™ would enable an urban courier to deliver about 10 percent more cargo volume in a day than the current vehicles. In order to exploit this improvement in productivity, the QuickSider™ must have at least 10 percent greater cargo capacity than the current vehicle. To accomplish this, the vehicle's wheelbase was increased from 140 in. to 147 in., which increased the overall length from 297 in. to 304 in., exactly matching the current vehicle in that dimension.

To examine the effects of body shape on aerodynamic drag, Unicell evaluated different body designs using Floworks, a commercially available Computational Fluid Dynamics (CFD) suite. First, Purolator's current vehicle and the Bodycote FE model were evaluated, resulting in a predicted drag of 1840 N and 990 N, respectively, at a velocity of 100 km/h. Design studies were conducted to explore how to shape the front and back of the vehicle to further reduce drag. The design shape with the lowest theoretical drag that was achieved had a predicted drag force of 600 N. There are practical constraints on how much shaping can be done to reduce drag, as these areas are important to the delivery operations of the truck and must accommodate a practically shaped windshield, front door and rear door. The final body shape has a drag of 640 N, as the windshield shape required for the 600 N body was determined by our windshield supplier to be unmanufacturable.

The final body shape was frozen in September 2005 and the CAD files sent to the toolmaker. All subsequent FEA work was done using the final body shape.

6.5.2. FEA of Prototype Body Shape and Resulting Design Iterations

With the final body shape frozen, the following questions regarding the structure of the QuickSider™ prototype were addressed:

1. What changes to the suspension connections and support beams would be necessary to eliminate the stress concentrations identified in Bodycote's analysis and bring all stresses below the design stress criteria of Table 4?
2. Packing work done after the Bodycote analysis resulted in the conclusion that two large, heavy components would need to be mounted in the vehicle's roof (i.e., the

motor controller and the radiator). What structures would be necessary to support these components and prevent unacceptable modal response in the roof?

3. Did the shape changes between the Bodycote model and the final body design cause any structural problems?
4. Were there any other changes that should be made to the Bodycote model in order to make it a better predictor of real-world behaviour?

To resolve these questions, Unicell's FE analyst worked with another automotive engineer specializing in chassis design.

6.5.2.1. Suspension Attachment Design Improvement

The suspension attachments were redesigned to address the problems shown in the Bodycote analysis. Several design iterations were completed, with each iteration subjected to FEA. Figure 12 shows the final floor structure design. Note the members added to bear the suspension forces in the wheelbox areas that are not present in the earlier model shown in Figures 10 and 11.

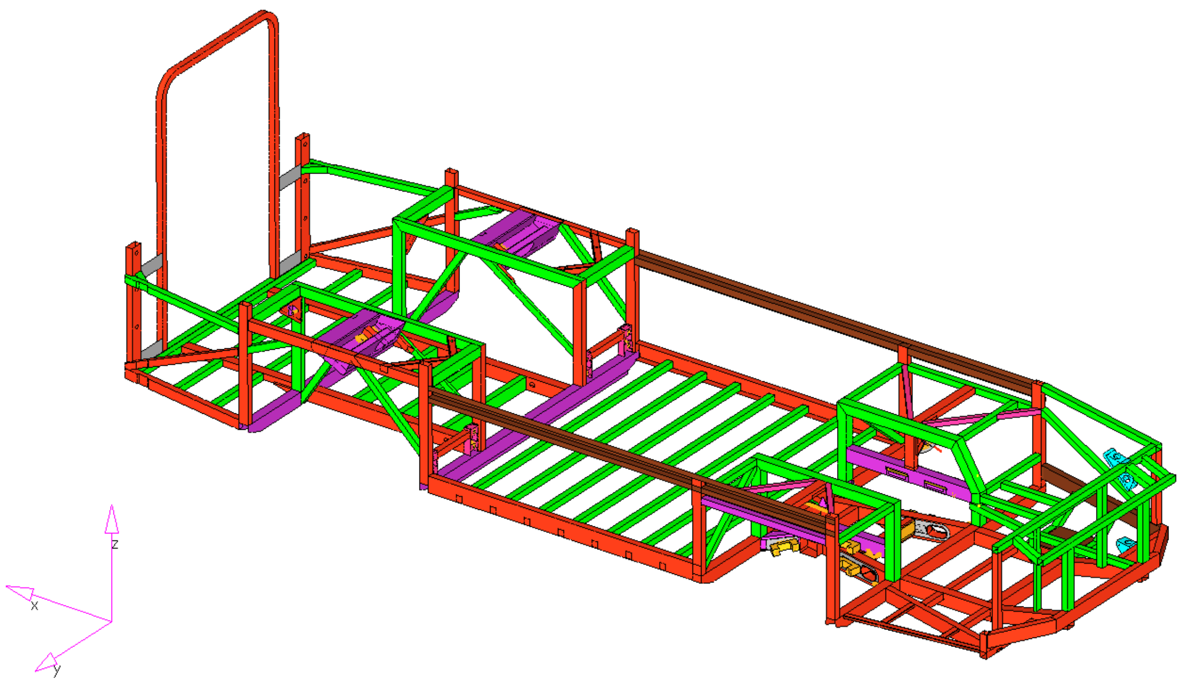

Figure 12: Final Floor Structure Design

Other structural details were changed in order to reduce the predicted stresses in the suspension attachment areas. Some of these are visible in Figure 14. Some of the tubes were reinforced locally with plates, gussets were added between some of the tubes, and the suspension attachment brackets were extended through the tubing so as to react the applied forces through two faces of the tubing rather than one. The effect of these changes on the maximum stresses in the structure can be seen by comparing Figure 14 to

Figure 11. Both figures show the front suspension structure subjected to a 1 g braking load (60:40 front to rear bias). The maximum stress shown in Figure 11 is 480 MPa, while maximum stress shown in Figure 13 is 160 MPa.

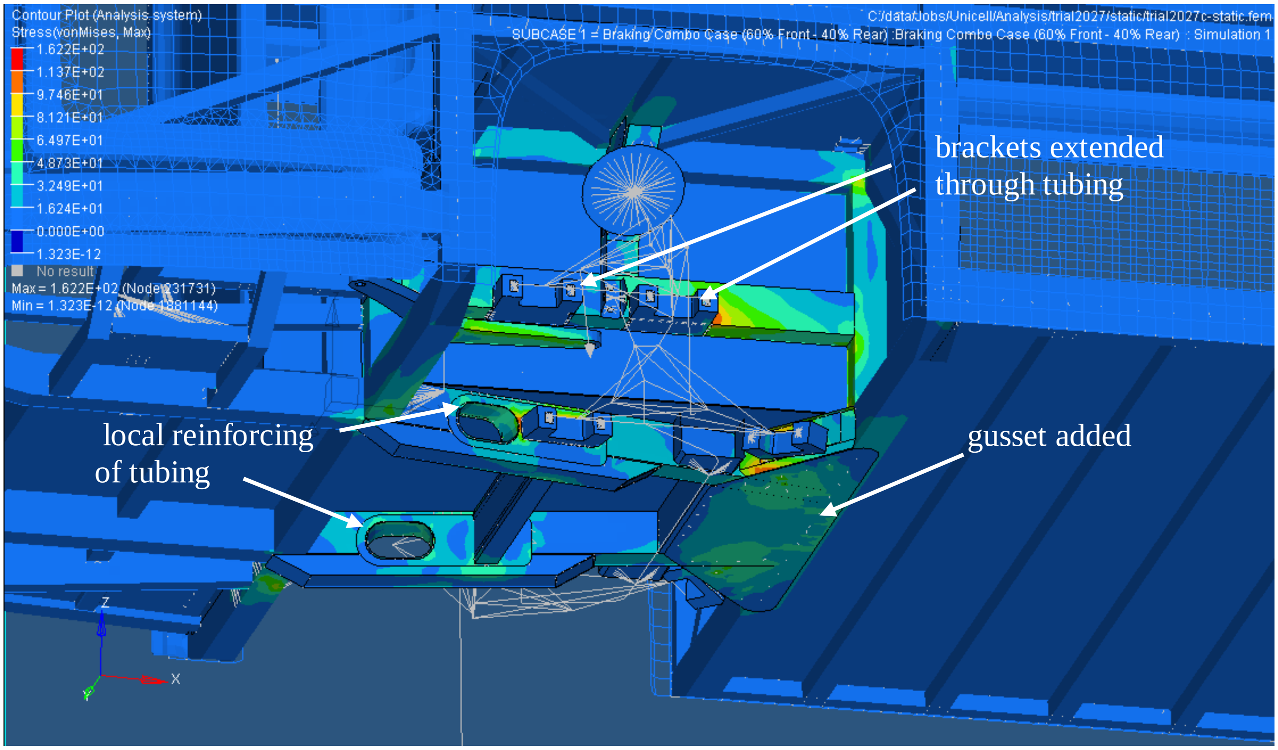

Figure 13: FEA Results, Front Suspension Structure, Loaded, 1g Braking

6.5.2.2. Design of Supports for Roof-mounted Components

It was decided by the design team that several of the prototype-only drive train components would be located in the roof of the demonstrator vehicle. These components were known to be much larger than those that would be used in the production vehicle; however, they were used in order to enable the vehicle testing to begin while the production versions of these systems were designed by ArvinMeritor. The components in question, along with their masses, are shown in Table 5.

Table 5: Roof-mounted Prototype Drive Train Components

Component	Location	Mass
Radiator	Roof (tub)	52 kg (114 lb.)
High Voltage Combination Box	Roof	28 kg (61.8 lb.)
Siemens Controller	Roof	65 kg (143 lb.)
Yaskawa Inverter	LHS Wall	24 kg (53 lb.)
230 V Electrical Box	LHS Wall	36 kg (79 lb.)

The radiator was mounted inside a tub moulded into the body skin, shown in blue in Figure 14, while the motor controller was mounted on the inside of the vehicle, secured to the longitudinal ribs indicated by the red arrows in Figure 14.

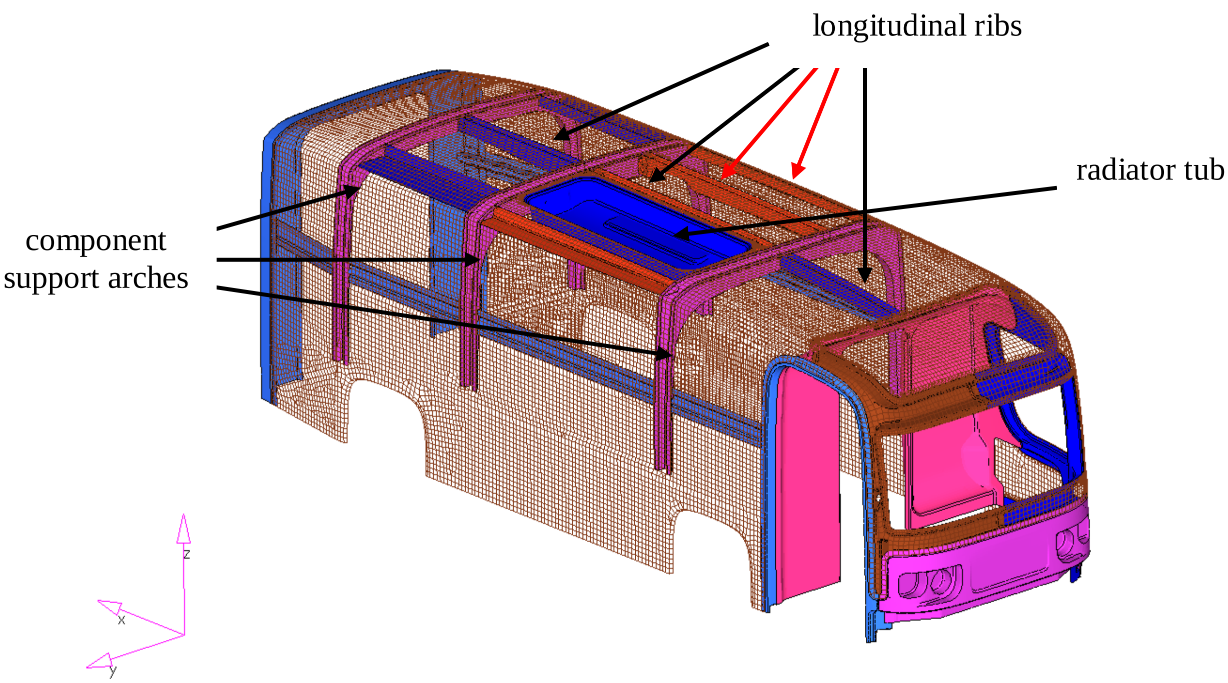

Figure 14: Fibreglass Structure with Roof Supports

As shown in Figure 14, the support system for these consists of the three “component support arches” interconnected with longitudinal ribs. This system must not only support the roof-mounted components statically and when the vehicle is subject to accelerations in all three dimensions, it must also prevent the roof and its attached components from resonating at low frequencies.

As with the floor structure, several design iterations were completed, with each iteration subjected to FEA.

6.5.2.3. Effect of the Final Body Shape on Structural Performance

The shape changes between the Bodycote model and the final body design did not cause any structural problems. In fact, the final analysis showed that the stresses in the body shell are quite low. Figure 15 shows the stresses on the body and its reinforcements when subjected to a 1 g vertical load. None of the stresses in the body structure exceed 5.74 MPa, or about 850 psi.

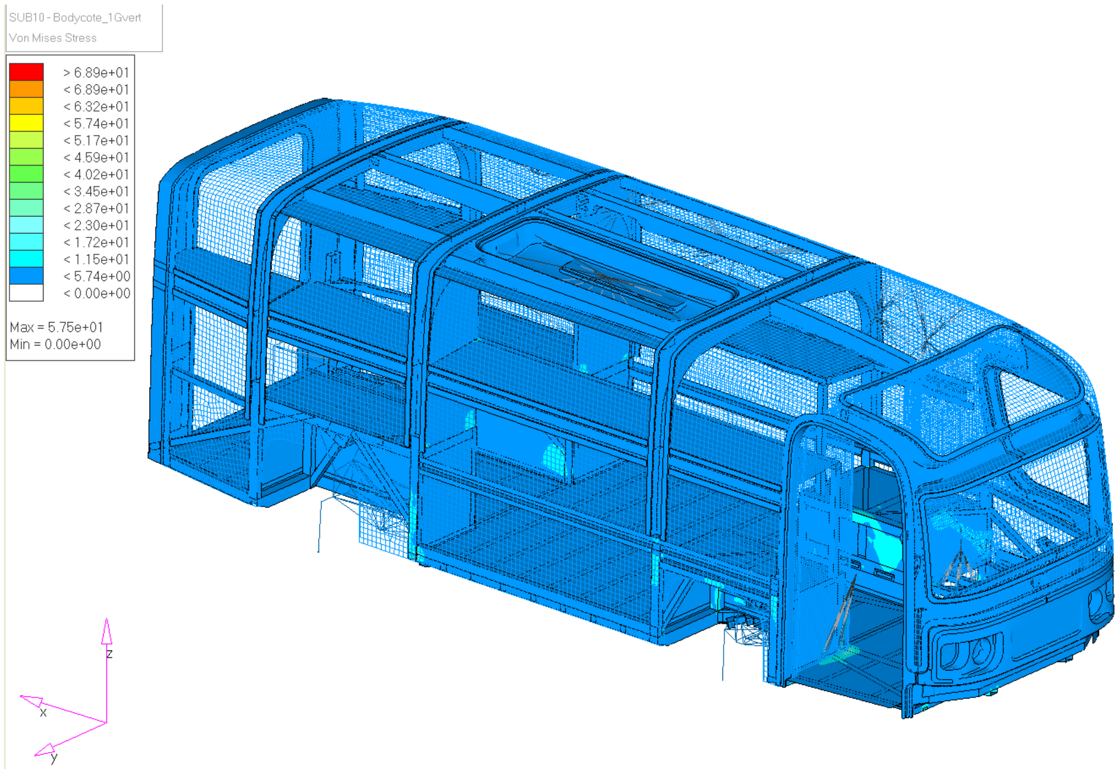

Figure 15: FEA Results, Prototype Model, Loaded, 1g Vertical

6.5.2.4. Other Refinements to the Bodycote FE Model

In addition to refinements to the vehicle mesh, the suspension model used by Bodycote was also refined. The properties of the suspension components were updated to reflect those of the actual components used in the vehicle. As well, the suspension models were updated to remove several over-constrained conditions that had resulted in unrealistically high stresses in some of the FE results in the Bodycote analyses.

Finally, an updated modeling approach was used to more accurately simulate the adhesive layer used to connect the composite components of the vehicle. The adhesive was simulated using solid elements, which were assigned properties corresponding to those of the adhesive. This allowed the model to quantify the effect of bond integrity and stiffness on the global structural performance of the vehicle.

6.5.3. Modal Analysis

Modal analysis was performed on the completed model, examining frequencies up to 60 Hz. One potential concern was found: a resonance at 11.68 Hz, in which the two sides of the front suspension resonate in phase vertically, as does the cabin. This is shown in Figure 16. It is desirable to decouple the body and suspension modes, which could be accomplished by stiffening the front end structure, reducing the mass of the front end, or a combination of both. This potential resonance will be monitored while testing the physical prototype and will be addressed in later designs.

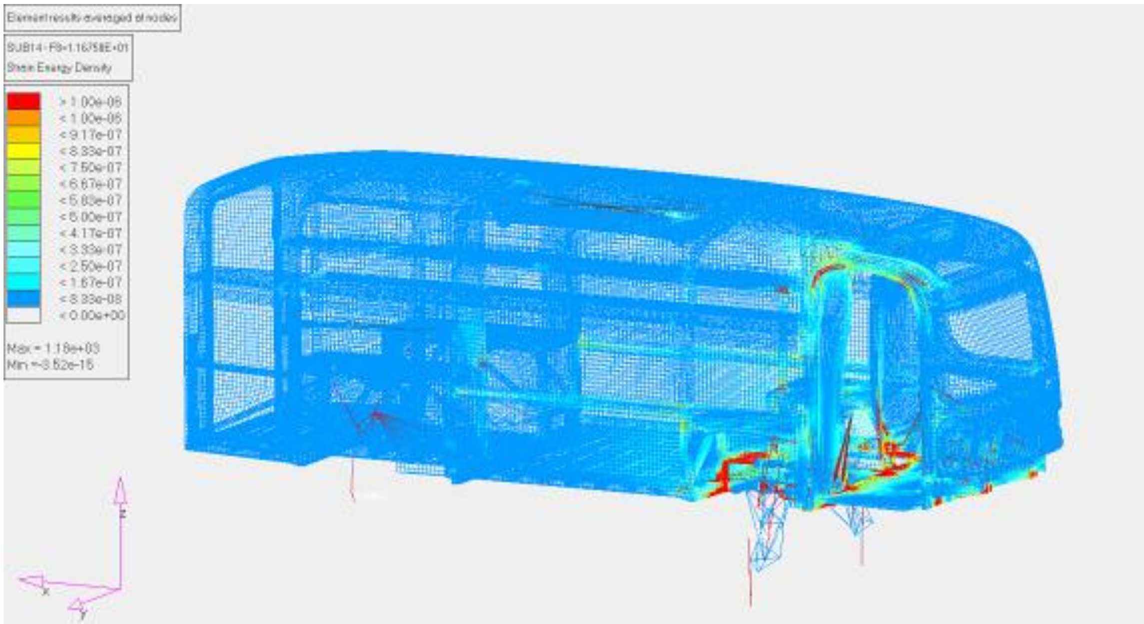

Figure 16: Modal Analysis, Mode 8, 11.68 Hz, Vertical

6.5.4. Prototype FEA and Design Iterations – Conclusion

The refined analytical model enabled the chassis design team to accomplish the following:

1. Eliminate the regions of high stress in the suspension attachments that were identified by the Bodycote model, bringing the maximum stresses below the Design Stress Criteria.
2. Stiffen the suspension support structures sufficiently to prevent deflections under load that would make the vehicle unpredictable to drive and therefore unsafe. The effect on wheel alignment of braking loads was given particular attention.
3. Design a structure to support the heavy roof components that were added to the vehicle design after the Bodycote model was created.

Addressing these three concerns was the highest priority in the design and FEA of the prototype, as these were issues of safety and the fundamental credibility of this “proof of concept” vehicle.

Relatively little time was spent in optimizing the structure. Unicell’s model, like Bodycote’s, indicated that, on the whole, both the fibreglass body and the stainless steel floor structure are quite lightly stressed, and could be made lighter. It is estimated that the body and the floor structure could be reduced in mass by about 35 percent and 25 percent, respectively, in the next iteration of the design by removing material from lightly stressed areas. The effect of these reductions on the overall weight of the vehicle is discussed in Section 6.6.

The FE model matches the prototype "as built" quite closely in the geometry of the "A" (finished) surfaces of the fibreglass components and in the floor structure. The "as built" prototype does differ from the FE model in some construction details that were worked out during assembly and, in some areas, with respect to fibreglass part thickness. These changes can be incorporated in the FE model if it becomes necessary. Unicell's FE analyst commented on this matter as follows: "The predicted global structural performance of the vehicle should be representative of the engineering prototype; however, detailed local results should be viewed with caution."

6.6. Conclusions Regarding the Structure

Figure 17 shows the QuickSider™ prototype. At the time of writing, the prototype has completed its track tests at PMG, which began in the fall of 2006 but were interrupted by battery failures and the onset of winter. Before resuming the test program, accelerometers and strain gauges were installed on the vehicle. This enabled correlation of the FEA model to the "as built" prototype.

Figure 17: QuickSider™ Prototype

The tests have been very encouraging with respect to meeting the three objectives outlined in Section 6.5.4: the vehicle handles very well, including during heavy braking, and no unsafe resonances or deflections have been detected anywhere in the structure, including the roof.

As noted in Section 6.5, much opportunity remains for optimizing the vehicle structure and reducing its weight. Table 6 shows the weight of the various systems of the QuickSider™ prototype as well as target weights for the next generation vehicle.

Table 6: Weights of Components and Systems of Prototype and Next Generation Vehicles

VEHICLE SYSTEM	Prototype Weight (lb)	Next Gen Target Weight (lb)	% Redn from Prototype
MONOCOQUE BODY			
Steel Structure	2,071	1,554	25%
Floor + alum panels	503	428	15%
Fiberglass structure	2,076	1,350	35%
Shelves	177	151	15%
Fr window	49	49	0%
Bumpers	65	65	0%
Doors	250	250	0%
Seat, dash, misc cab	150	150	0%
	5,342	**3,996**	25%
DRIVE TRAIN INCL REAR SUSPENSION			
	2,375	**2,062**	13%
FRONT SUSPENSION INCL STEERING			
	1,186	**1,186**	0%
AUXILIARY SYSTEMS			
	439	**201**	54%
BATTERY SYSTEM			
	2,260	**1,388**	39%
Total Vehicle Curb Weight	**11,602**	**8,832**	24%

Brief summaries of the weight reduction plans to achieve the results in this table are as follows:

1. **Monocoque body.** As reported in section 6.5.4., it is estimated that the next iteration of the design/FEA cycle, which will be focused on weight reduction, will yield 25 percent and 35 percent, respectively, in weight reductions in the floor and body structures. Part of the reduction in the weight of the body structure will be accomplished by eliminating the structures used to support the heavy components that are mounted in the roof of the prototype but will be mounted in the wheel wells of the next generation design.

2. **Drive train, including the rear suspension.** At the time of writing, ArvinMeritor is developing its next generation drives for the QuickSider™. The drives themselves are lighter than the prototype ones, as are the motor controllers and cooling systems that support them. The controllers and radiators for the new drives will be housed in the rear wheel wells rather than the roof, which will have three important benefits: a lower centre of gravity, a more aft centre of gravity, and much shorter, and therefore lighter, power cables and coolant lines.

3. **Front suspension, including steering.** At the time of writing, a preliminary search is being made for an "I" beam front suspension to fit the QuickSider™. Such suspensions are used in some low-floor buses. They are simpler and cheaper than "A" arm suspensions and transfer less load to the chassis, thereby allowing the suspension attachment system of the chassis to be simpler and lighter. Such a suspension would also likely allow simplification and lightening of the steering system.
4. **Auxiliary systems.** These systems include the air compressor, brake and power steering pumps, AC inverters, 12V and 24V batteries and the cab heater. Most of these components were deliberately oversized on the prototype in order to determine required real-world capacities. These will be reduced in size based on what is learned in testing the prototype. Some components, such as the 24V batteries and the large AC inverter, will be completely eliminated.
5. **Battery system.** The prototype uses Zebra NaNiCl traction batteries. It is likely that these will be replaced by much lighter Li-ion batteries in the next generation vehicle.

The prototype monocoque body did not achieve the initial target weight of 3500 lb., largely because, as explained in Section 6.5.4, the primary focus of the structural design team was on the highly stressed areas of the vehicle. It is expected that the next generation vehicle will be much closer to the target weight, as demonstrated in Table 7.

Table 7: Body/Chassis Weights vs. Industry Benchmark

Body/Chassis Type	Weight (lb.)	Reduction from Benchmark
Utilimaster/Ford (benchmark)	5500	0%
QuickSider™ Target	3500	36%
QuickSider™ Prototype	5342	3%
QuickSider™ Next Gen	3996	27%

In conclusion, at the time of writing, it appears that the design process, critically informed by FEA, has resulted in a vehicle that is structurally sound and safe. The highly stressed areas of the vehicle have received the most design attention and their design is close to optimal. The lightly stressed areas of the vehicle have received relatively little design attention so far. The FEA model, correlated by accelerometer and strain gauge data from the prototype tests, will inform the optimization of these areas in the next stage of the vehicle design.

6.7. Investigation of Composite Floor Materials

Although there is no practical experience of all-composite commercial delivery vehicles, the use of composites in the floor structure of the QuickSider™ is attractive for the following reasons:

- Composite structures are potentially lighter than metal ones.
- Composites are inherently non-corroding and have good insulating properties.
- The QuickSider's body structure is all-composite so that an all-composite floor structure could be easily integrated with it.

At least one bus, the NABI CompoBus, has been constructed using an all-composite design, including the floor and wheel wells.

From the beginning of the QuickSider™ design process, both composites and metals were considered for the floor design. It was eventually decided to build the prototype using a stainless steel floor structure for the following reasons:

- It was known that there would be very high stress concentrations at the suspension attachment points and that there is very limited allowable deflection at these points because of the need to maintain acceptable wheel alignment under all loading conditions.
- While there was available expertise within the Unicell design team and Bodycote to design and analyze the structure necessary to deal with these demanding constraints in stainless steel, there was no equivalent expertise available for composite structures of the required performance.
- The tooling costs to build a one-off stainless steel structure are low relative to those required to make a one-off composite structure.
- The development time required for a successful composite floor structure was uncertain and estimated to be at least a year, as compared to a few months for the stainless steel structure.

Although the decision was made to make the prototype floor structure from stainless steel, the design team decided to investigate two possible composite structures for future use in the large floor panel between the front and rear wheel wells. Unicell engaged Bélanger.com to study possible design approaches. After reviewing available composite materials appropriate for use in the floor panel, Bélanger.com recommended that two solutions be investigated:

1. A bonded structure using Martin Marietta's TRANSONITE composite panel material and pultrusion brackets, and
2. A moulded structure using Webcor Technologies' TYCOR fibreglass-reinforced foam core material.

Bélanger.com engaged Precicad Inc. to help develop these solutions in CAD and to do appropriate FEA. Figure 18 shows Precicad's FE model of the prototype's stainless steel/aluminum floor panel under a 6000 lb. load, while Figure 19 shows a composite structure base on a TRANSONITE panel under the same load.

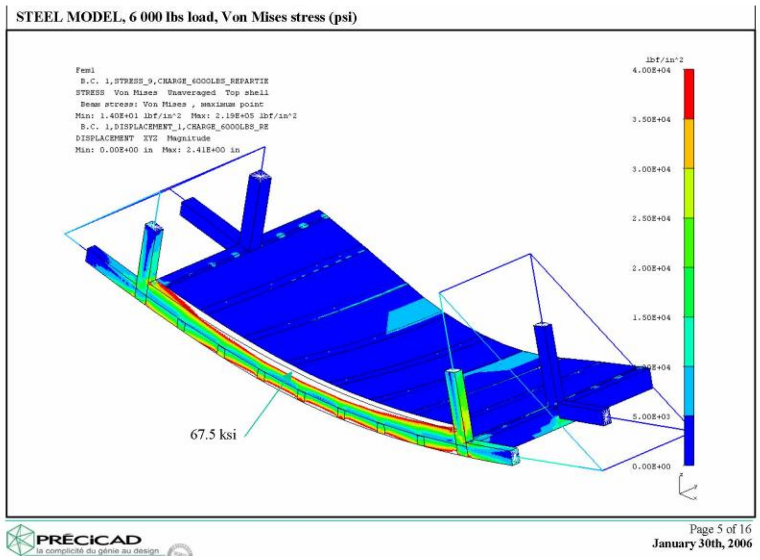

Figure 18: Precicad Steel Floor Structure FE Model Deflections (6000 lb. load)

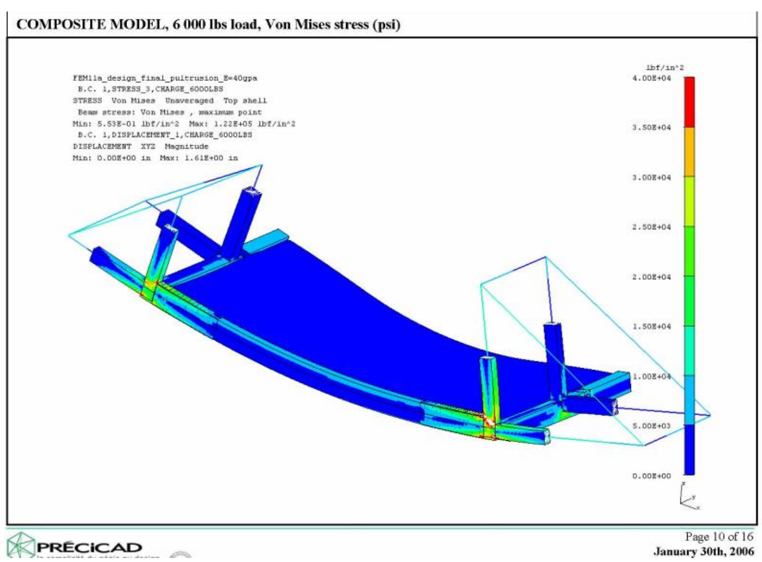

Figure 19: Precicad Composite Floor Structure FE Model Deflections (6000 lb. load)

Bélanger.com's FEA work with Precicad indicated that a composite floor panel could be made that would match the structural properties of the stainless steel/aluminum floor with significantly less weight. To validate this FEA work, full-scale physical models were made of the stainless steel/aluminum and the composite panels, which are shown in Figures 20 and 21.

Figure 20: Physical Model of the Stainless Steel/Aluminum Panel

Figure 21: Physical Model of the Composite Panel

The two panels were then loaded as shown in Figure 22 and their deflections measured.

Figure 22: Composite Panel Under Load

The physical tests validated the FE work done by Bélanger.com and Precicad, so that Bélanger.com was able to estimate that composite panels could be made that would compare to the stainless steel/aluminum panel in weight and cost as summarized in Table 8.

Table 8: Comparison of Estimated Panel Weights and Costs

Panel Type	Weight	Cost to Manufacture
Stainless Steel/Aluminum	375 lb.	$1500
TRANSONITE	250 lb.	$1900
TYCOR	225 lb.	$900

These results indicate that the TYCOR panel has the lowest weight and cost when the panels are looked at in isolation from the rest of the floor structure. However, the flat panel is only part of the overall floor structure. The need to integrate the panel with the front and rear wheel box structures would entail costs as yet unknown. It is far from certain that composites offer the lowest cost solution, although these results are encouraging. Further research and development will be required to resolve this issue. Such further work appears justified by the results to date.

6.8. Recommendations Regarding Further Development of the Vehicle Structure

We recommend that:

1. Accelerometers, strain gauges and supporting instrumentation be installed on the prototype so that the FEA model can be correlated to the "as built" prototype.
2. In the next round of vehicle design, focus be placed on structural optimization and weight reduction.
3. The possibility of a future all-composite design of the body and floor be investigated further.

7. Development of the Energy Storage System

This work was done by Unicell Limited and Battery Engineering & Test Services Inc. under contract to Unicell. A simple spreadsheet energy model was used to develop the vehicle power and energy requirements. Low drag body shapes were investigated to minimize the highway power requirement and extend vehicle range. BET prepared the battery SOR, searched for battery suppliers potentially capable of meeting those requirements, distributed the SOR to some 30 potential suppliers, evaluated the responses received, recommended the Zebra battery as the best available solution, carried out acceptance testing of the four Zebra batteries procured for the project, and installed them in the QuickSider™ prototype.

Of the 30 potential battery suppliers, only 5 responded, and only the proposal from Electrovaya Inc. warranted inclusion in the prototype testing program. Electrovaya is preparing a set of batteries designed to meet the SOR that will be available for testing in the QuickSider™ prototype later this year.

As part of the QuickSider™ project, Unicell prototyped the leasing process that allows the cost of batteries to look like the cost of fuel for conventional vehicles on its customers' financial statements. A set of four Zebra batteries was procured by Southwestern Energy Inc., a division of Halton Hydro, and these have been leased to Unicell for the term of the prototype test program. Current work includes validating one or two more potential battery suppliers. A methodology for evaluating battery costs against current fuel costs was developed.

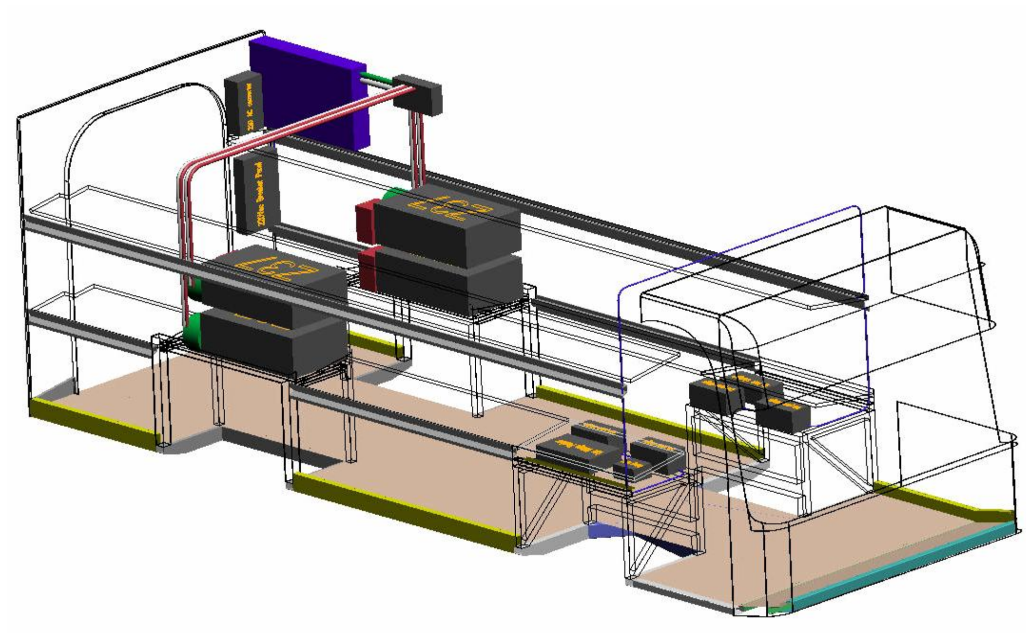

Figure 23: BET Series B4Z Battery System Installation

7.1. Vehicle Energy Model

The QuickSider's design objective was to meet or exceed all useful and measurable performance characteristics of the current body and E450 chassis with its 5.4 L gas engine. Some of those key measures are shown in Table 9.

Table 9: Targeted Performance Characteristics for the QuickSider

Measure	Value	Source
Acceleration	0 to 100 km/h in 18 seconds	Customer
Top Speed	120 km/h	Customer
GVWR	16,500 lb.	Customer payload + chassis + batteries
Range	60 km	Observed maximum urban route length
Minimum Temp	-30ºC	Yellowknife weather data

The spreadsheet shown in Table 10 was created to take the vehicle configuration parameters and requirements and solve for peak power, average power and total energy required.

Table 10: Power and Energy Requirements for the QuickSider

Power and Energy Requirements for the Quick Sider										
This sheet takes as input the type of low floor vehicle configuration, delivery parameters,										
vehicle weights and performance and returns power and energy requirements for components										
MODE	7			Actual lifetime						
		Engine/generator	Fuel Storage	Elect Storage	Storage type	CdA	Area	Plug-in	Body & chassis	Regen
Mode Designation	Model	& fuel tank weight	gallons/H2(kg)	kWh	Pb/UCap/LiPo		m^2	y/n		available
mode 0 - Current Diesel Engine - no regen	16 Foot Walk-in	1500	36	0	none	0.647	6.11	n	6500	0%
mode 1 - serial diesel hybrid with ultra caps	16 Foot Walk-in	1300	36	0.7	Ucap	0.647	6.11	n	6500	20%
mode 2 - serial diesel hybrid with batteries	16 Foot Walk-in	1300	36	10	Pb	0.647	6.11	n	6500	30%
mode 3 - serial diesel hybrid with ultra caps	Quick Sider	1787	36	0.7	Ucap	0.375	5.15	n	6169	20%
mode 4 - serial diesel hybrid with batteries	Quick Sider	1787	36	20	Pb	0.375	5.15	n	6169	30%
mode 5 - plug-in serial diesel hybrid with Pb acid batteries	Quick Sider	1787	10	20	Pb	0.375	5.15	y	6169	30%
mode 6 - plug-in BEV Pb acid max 20 kWh	Quick Sider	1097	0	20	Pb	0.375	5.15	y	6169	30%
mode 7 - advanced BEV - Lithium Polymer pack	Quick Sider	1097	0	40	LiPo	0.375	5.15	y	6169	50%
mode 8 - advanced BEV with solar assist	Quick Sider	1127	0	40	LiPo	0.375	5.15	y	6169	50%
mode 9 - Fuel Cell HEV - with LiPo battery pack	Quick Sider	2500	4	0	none	0.375	5.15	n	6169	50%
UNDER TEST:										

Factors considered in the energy calculation were aerodynamic drag, battery efficiency, rolling resistance, heating and auxiliary loads, acceleration, regeneration and cornering losses, as shown in Tables 11 and 12.

Table 11: Vehicle Power and Energy Output

		Engine/	Solar	Balance	Total	
Energy Used in kWh for Mode under test	Plug-in	Generator	Input	in pack	used	
mode 7 - advanced BEV - Lithium Polymer pack	40.0	-	-	5.9	**34.1**	**kWh**
Note: mode 6, 7, 8 negative balance in pack number is a failure				**or**	**0.90**	**kWh/mile**
			mode 0	mode 5	mode 7	
	Loss J	kWh	Diesel	Plug-in	Advanced	
Collect Losses due to			Diesel	Diesel HEV	Advanced EV	
Acceleration	42,681,714	11.9	22.2	14.6	11.7	
Drag	25,187,708	7.0	14.3	7.0	7.0	
Tires	23,461,547	6.5	6.5	8.0	6.4	
Heating	22,437,496	6.2	0.0	0.0	6.0	
Accessories	8,370,000	2.3	0.4	0.4	0.4	
		33.9				

Table 12: Vehicle Power Output

Estimated Peak Power Requirements	**kW**
Peak power input for City driving, accelerating near full speed	129
Power input for Highway driving with 3% grade	82
Power input for Highway driving	37
Power input to accelerate to 100 km/h at curb wt in 18 seconds	120
Power for heat including air exchanged during door openings (in addition to above)	2.6

The energy and power model indicated that a 40 kWh battery with a minimum of 120 kW peak power would be sufficient for this first 60 km QuickSider™ configuration. A pack with a 60 kWh energy capacity was chosen to provide a safety margin for the unexpected during the test phase. The QuickSider™ prototype's primary reason for being is to solve the problems of an electric delivery vehicle and ultimately to evaluate the business case for moving to production. It was prudent to err on the side of being able to complete the daily deliveries than to cut it too fine and risk a major project setback. The Zebra batteries have a rated power capacity of 36 kW and an energy capacity of 19 kWh each.

While three batteries would have been sufficient for the expected energy requirement plus a generous safety margin, they would not satisfy the power requirement. Four Zebra batteries were selected to deliver 144 kW of power thereby exceeding our 120 kW expected power requirement. As shown in Table 6, the QuickSider™ prototype exceeded the expected curb weight, which meant that the prototype could not achieve the 18 second 0 to 100 km/h time. The team is confident that the weight can be reduced and that the current power available from the Zebra pack is sufficient. Alternative battery suppliers such as Electrovaya claim to be able to deliver 120 kW of power from a battery pack as small as 40 kWh of energy. It remains to be seen whether 40 kWh is sufficient to deliver a 60 km range. The rated range must be conservative to allow for cold weather heating loads, poor driving technique and some contingency for traffic jams and construction. The impact of these issues will be explored during the on-road test phase.

7.2. Development of a Low Drag Body Shape with CFD

The current expense and low energy density of advanced batteries meant that energy efficiency was a high priority during the development of the QuickSider™ prototype. The team used CFD to do a search for practical low drag truck shapes. Over 50 3D CAD models were created and tested. The current curbside delivery truck tested out at approximately 240 percent of the drag of the final QuickSider™ body shape in comparative CFD testing. Shown below are velocity plots of the airflow around the 3D CAD models. These results were produced in Cosmos Floworks. Slow air is shown in blue, 100 km/h air is green and high speed air accelerated by body surfaces is shown as red.

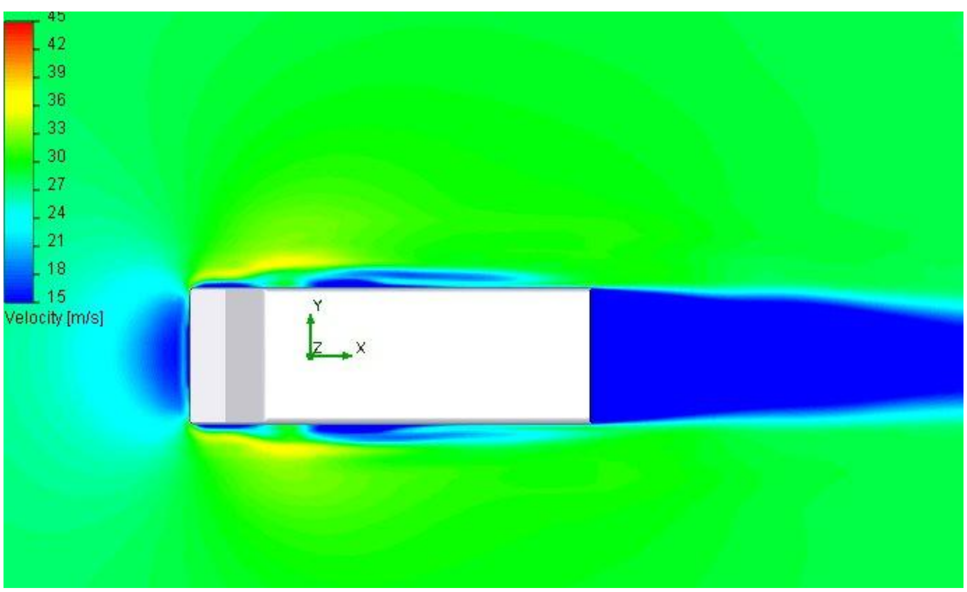

Figure 24: Current Curbside Delivery Van, Top View (1,550 N drag @ 100 km/h)

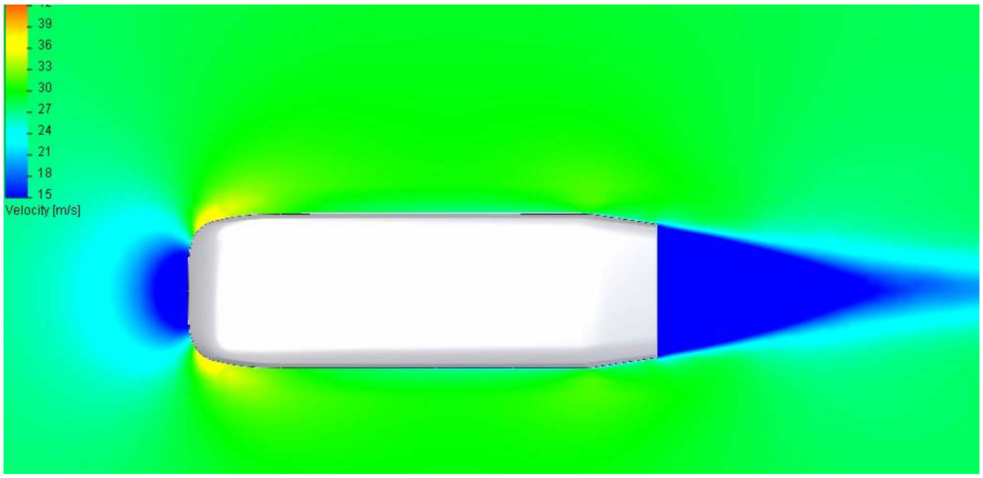

Figure 25: QuickSider™ Prototype, Top View (650 N drag @ 100 km/h)

Preliminary Environment Canada dynamometer test results indicate that the real-world aerodynamic drag of the current curbside deliver vehicle is approximately 200 percent of the QuickSider™ due to the smaller frontal area and this aerodynamic optimization work. Aerodynamic drag is the dominant loss at highway speed. This should increase the highway-only range by 90 percent. The Purolator driving cycle is dominated by city stop-and-go cycles with only short highway stem times at the beginning and end of each shift. The model predicts a 27 percent increase in range due to improved aerodynamics on the Purolator cycle.

7.3. Work Performed by BET

7.3.1. Phase 1: Battery Specification

BET Services was contracted by Unicell on February 14, 2005, to complete a set of tasks described as Phase 1. These tasks included:

- Collecting relevant battery standards and best practices
- Developing a battery-focused list of customer wants and needs as driven by Unicell vehicle customer wants and needs
- Establishing design goals and an SOR to evaluate other battery systems
- Reviewing size selection and packaging for a comparison of the BET NaNiCl Battery System to the SOR
- Providing battery-focused technical support on site at Unicell during the design stage
- Preparing an RFP for selection of a battery system

BET met with Unicell both at BET facilities in Mississauga and at Unicell facilities in Toronto on seven separate occasions in the execution of this phase.

BET employed its in-house resources in battery systems; electrical, electromechanical and electronic engineering; electric vehicle installations; systems integration; and program management. BET and Unicell worked cooperatively at Unicell to brainstorm and develop optimum packaging options for the battery system installation that would best meet the customer's requirements.

7.3.1.1. Codes, Standards and Best Practices

BET gathered all known North American codes, standards and regulations that may apply to the battery system in a vehicle such as the QuickSider™. Some of these documents were already in BET's possession, but several had to be acquired and reviewed. In general, the charger portion of the battery system must meet and be certified by CSA, ULC or UL depending on whether the market is in Canada or the U.S. CMVSS/FMVSS requirements must also be met for material flammability. SAE has several applicable guidelines that are self-certified. USCAR is guideline only.

The listing provided does not assess whether the prototype battery system installation will meet the codes. This requires consultation with the relevant bodies and may involve substantial cost.

7.3.1.2. Defining the Product Outcome

BET uses a product definition process that helps ensure that product design objectives are captured prior to the start of product design activities. This involves first developing the Customer Wants and Needs (CW&N) for the vehicle, as seen by Unicell. From these CW&N, the battery system CW&N was developed with Unicell. The third step is to assign specific and quantitative (where possible) design targets. The visibility that this process brings helps ensure that, as new customer requirements are developed during the design process, they are captured and expanded to design goals.

7.3.1.3. Packaging Challenge

The battery model selected for the application was based on the system voltage and power requirement. Initial battery system layout in the vehicle was the simplest by placing the four batteries on the vehicle floor between the wheel boxes. However, after user reviews with this arrangement mocked up, a layout with the batteries over the rear wheel boxes, which preserved vehicle floor space for payload, was selected (see Figure 23).

7.3.1.4. How the BET NaNiCl Battery System Measures up to the SOR

The BET Series B4Z battery system meets most but not all of the SOR line item target values. However, at the time of writing, it is the only battery system that provides workable levels of power and energy, is available and safe, has a warranty, and can be packaged for the project prototype.

7.3.1.5. Concept Technical Support

The BET Core Team met with the Unicell Team for three sessions on site at Unicell. Various packaging options were developed and evaluated. The final configuration showed the best results in terms of floor space infringed, cabling lengths, ease of battery handing, packaging freedom for direct battery system components, and electrical safety.

7.3.1.6. Search for Better Batteries

An SOR was developed to assist in searching for acceptable battery solutions. An RFP including the SOR was prepared and issued to some potential battery system suppliers. The list of potential suppliers is included as Appendix A, and BET's evaluation of the responses to the RFP received is included as Appendix B.

7.3.1.7. Phase 1 Conclusion

Out of the work undertaken in this phase, a battery system concept and installation scheme has been developed by BET that promises to meet or exceed many of the vehicle level customer wants and needs. Detailed design will determine the final assessment as to whether all customer wants and needs will be met in the prototype. All of the groundwork needed to launch the RFP for a better battery has also been completed.

7.3.2. Phase 2: Battery Preparation

BET completed Phase 1 of the Unicell QuickSider™ project in March 2005 and was contracted by Unicell on June 28, 2005, to complete the next set of tasks for the project, described as Phase 2. These tasks included:

- Conducting a high-level evaluation of the Phase 1 RFP for selection of a battery system
- Providing battery handling, care, and maintenance guidelines
- Providing a "Black Box" BET Series B4Z Zebra battery system for the QuickSider™ prototype, including wiring, installation, and start-up

All of these tasks were completed by April 19, 2006, the deadline issued by Unicell for when the vehicle was shipped to ArvinMeritor. However, one of the four batteries installed by BET was not charging correctly. This was not resolved prior to the emergence of additional problems with the batteries and chargers in November 2006. Since then, two of the batteries have been replaced and three of the chargers are being repaired.

BET met with Unicell both at BET facilities in Mississauga and at Unicell facilities in Toronto on many occasions in the execution of this phase, including on site support at ArvinMeritor in Troy, Michigan. BET employed its in-house resources in battery systems; electrical, electro-mechanical and electronic engineering; electric vehicle installations; systems integration; and program management. Along with ArvinMeritor, BET and Unicell worked cooperatively to develop the best options for the installation of, and interfaces to, the battery system.

7.3.2.1. Evaluation of the RFP

An SOR was developed in Phase 1 to assist in the search for and evaluation of other battery systems. In Phase 2, an RFP including the SOR was assembled and used to invite 42 potential battery system suppliers to propose their systems. The RFP was released in mid-July 2005, with proposals due by Sept 2, 2005, (i.e., a six-week response time). Despite telephone calls and e-mails, only 5 suppliers chose to formally respond to the RFP. A report was issued by BET to Unicell outlining the supplier list, efforts taken by BET to contact the suppliers, and the subsequent responses. In addition, a separate report was also issued by BET in which the information from each respondent was evaluated through a qualitative assessment using scales for ranking. A separate meeting was held by Unicell (along with BET and ArvinMeritor) directly with Electrovaya to evaluate its systems.

7.3.2.2. Battery Handling Guidelines

On February 8, 2006, two staff members from Unicell, one from Rhinnovations, and four from ArvinMeritor attended a training session on site at BET focusing on battery handling issues. The session included a review of an actual working battery and its components, and the main components of an actual, individual cell, as well as a 25-page handout. The session was very well received and subsequent comments indicated that many questions about the battery system had been answered.

7.3.2.3. BET Series B4Z Battery System

The BET Series B4Z battery system, along with all of the relevant components, was installed onto the prototype QuickSider™ vehicle by BET personnel in April 2007. This included:

- Battery and Battery Management Interface (BMI) Serial Numbers: 021 and 10916; 023 and 10914; 024 and 10915; 025 and 11075
- Charger Serial Numbers: 00811; 00812; 00813; 00814
- Multiple Battery Server (MBS) Serial Number: 2005

Initially, the vehicle was planned to be delivered to BET for two weeks in December 2005 for the wiring and installation of BET components into the vehicle. The timing was later changed by Unicell to a one-week period in April 2006 that was later extended to two weeks. Also, due to a change made late in Phase 2, the BET system was requested by Unicell to be installed at Unicell's facilities instead of at BET. In order to expedite the process and minimize potential issues during the installation at Unicell, the entire system was wired, connected and tested at BET's facilities, then dismantled for shipment.

Installation of BET components began on schedule at Unicell on April 3, 2006, as requested by Unicell. The 12 V and AC Heater systems (including the BET 240 V Breaker Panel, BET 12 V Fuse Box, signal and 12 V power to the MBS and all BMIs, and the BET CAN network) were systematically checked by BET at Unicell facilities using a BET-supplied power supply on April 12, 2006. 240 VAC off-board power was used on April 13, 2006, to heat the batteries and power the MBS, BMIs, and BET 12 V systems. From April 22 to 24, 2006, the batteries were heated to operating temperature while at ArvinMeritor, and three of the four batteries were charged. The contactors on all batteries were able to be closed, thus providing nominal 600 VDC to the disconnect switch. At the time of this report, investigations into the reasons the fourth battery did not charge had not yet begun.

During the wiring/installation/start-up period of the BET battery system in the prototype vehicle at Unicell, a significant number of unforeseen issues were encountered. All issues were overcome in a timely manner by BET so that the installation of BET components was completed before the April 19, 2006, the scheduled date for shipping the vehicle to Arvin Meritor.

Major Issue

- The decision to install the BET system into the prototype vehicle at Unicell's facility rather than at BET's facility as originally planned led to additional travel time and expenses, including the frequent pick-up and transport of components and hardware between BET and Unicell. In addition, to accommodate the changing cable routings made by Unicell during the installation, wire and cable lengths were changed several times (along with the resulting change of pins and connections), causing considerable lost time. Also, while the vehicle was at Unicell, testing of the 240 VAC BET system forced work to be completely interrupted on the rest of the vehicle. Additional costs to ship the batteries to Unicell were incurred, and the resulting delays allowed the batteries to discharge and cool, which prevented testing of the high-voltage (620 VDC) systems. This would not have been the case if the battery system had been installed at BET's facility.

Moderate Issues

- Significant effort was spent by Unicell, Rhinnovations, and BET to design a BET Splitter Box and related cable routing and box mounting when some design and dimensional information from the original splitter box supplier proved to be incorrect. Ultimately, the box design was changed after placement of the initial order and it was delivered directly to Unicell at the end of the first week of the installation of BET components at Unicell.
- The physical installation of the traction batteries into the prototype vehicle took slightly longer than anticipated. This was because several bulkheads were installed to hold BET charging equipment and cables, but this requirement was not included in the vehicle design and dimension drawings supplied to BET when they designed the battery installation apparatus. The apparatus was successfully reworked on site at Unicell to allow the installation.

Minor Issues

- While supporting initial test efforts at ArvinMeritor's facilities in Troy, Michigan, the BET network controller hardware (MBS) was damaged, likely due to incorrect grounding by ArvinMeritor. A spare MBS owned by BET was then supplied to Unicell to allow the project to continue with little interruption.

- In the week immediately prior to the installation of the BET system at Unicell's facility, Unicell was still developing and making changes to component placement and mounting, and cable routing. For example, after other hardware had already been procured and wired by BET, Unicell accepted a BET suggestion to change from the use of four charger fuse boxes to two charger fuse boxes so that BET components could fit more easily between the newly designed vehicle bulkheads. Also, Unicell made the decision that no cable "trays" were to be used to route cables. Therefore, after other cable hardware had already been procured and used by BET, the charger cables had to be changed.

7.3.2.4. Phase 2 Conclusion

The BET Series B4Z battery system was successfully installed in the prototype QuickSider™ during the time frame specified by Unicell. Minor, moderate, and major issues were all overcome, with the most significant issues arising due to the installation of the BET system at Unicell rather than at BET. See Appendix A for the advanced battery vendor RFP list and results summary.

7.4 Current Battery Economics

One of the ideas developed to understand the economics of a battery electric vehicle (BEV) is mobile energy cost. Mobile energy is defined as the energy delivered from the main power source to do useful work. In the case of a BEV, that energy is delivered over wires from the traction batteries. In the case of an internal combustion engine (ICE), that energy is delivered through a mechanical drive train.

The efficiency in a conventional urban delivery truck application is approximately 10 percent, so the ICE mobile energy cost is approximately 10 times the required traction energy cost. For the BEV, the electricity costs are straightforward; however, the battery is a very expensive consumable item, and must be included in the BEV mobile energy cost. Battery cost, calendar life, cycle life, daily depth of discharge (DDOD), efficiency (expected to be 80 percent in the case of the Zebra batteries), and input electricity cost were used to arrive at the total BEV mobile energy cost. Thinking in terms of mobile energy cost as defined above allows a direct comparison of the current costs of operating ICE and BEV vehicles with comparable capacities.

The DDOD was found to have a large impact on the BEV mobile energy costs. In this application, we can size the battery so that the DDOD will be 60 to 80 percent. At 80 percent, this will provide a 20 percent reserve for daily variations in route demands. The Zebra batteries leased for the prototype QuickSider™ are expected to have a five-year or 1000 full cycle warranty, although this business agreement is yet to be formalized or tested in practice. At 80 percent DDOD operated 250 business days per year, the 1000 cycle limit will be reached at the same time as the expected calendar life of five years. Alternatively, if an application used only 20 percent DDOD, then the five year expected life would be the limiting factor. The actual grid electricity costs are very small in comparison to the battery leasing cost prorated over the energy delivered. Therefore, the mobile energy cost would quadruple in the 20 percent DDOD application as compared to the 80 percent DDOD application. Based on current cost factors and trends, it appears that BEV applications that have a high DDOD, such as the QuickSider™, will soon become economically viable.

8. Development of the Electric Drive

ArvinMeritor has worked in parallel with Unicell over the past two years to develop the drive train, suspension and steering systems for the QuickSider™. The front suspension is a product originally developed in Europe and in use today on the Optare bus built in the UK. The rear suspension, with its integrated drive train, is a new development undertaken by ArvinMeritor specifically for the QuickSider™. The liquid-cooled Siemens traction motors in the prototype provide the required performance but are too expensive for production and will be replaced by a lower cost, lighter, more integrated system now under development. ArvinMeritor also developed the auxiliary drive for the steering and pneumatic systems of the prototype. These, too, will be replaced by lower cost, lighter alternatives in the production vehicle.

8.1. Choice of Drive Configuration

Unicell's contribution to the ArvinMeritor Drive System included original trailing arm concepts such as the one shown at Figure 26.

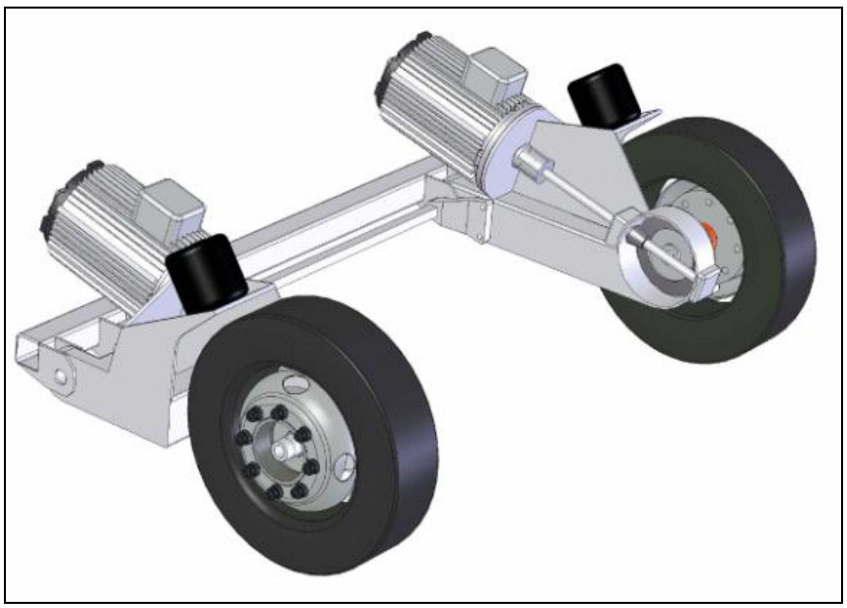

Figure 26: Unicell's Swing Arm Rear Drive Concept

ArvinMeritor, in consultation with Unicell, examined a rigid front wheel drive axle, an independent all round suspension with front wheel drive, an inverted portal axle, and an independent light version of their commercially available ultra low floor axle (ULFA) before settling on the dual independent swing arm concept incorporated into the prototype QuickSider™.

Figure 27: ArvinMeritor's Portal Axle

Figure 28: ArvinMeritor's ULFA Electric Drive Axle

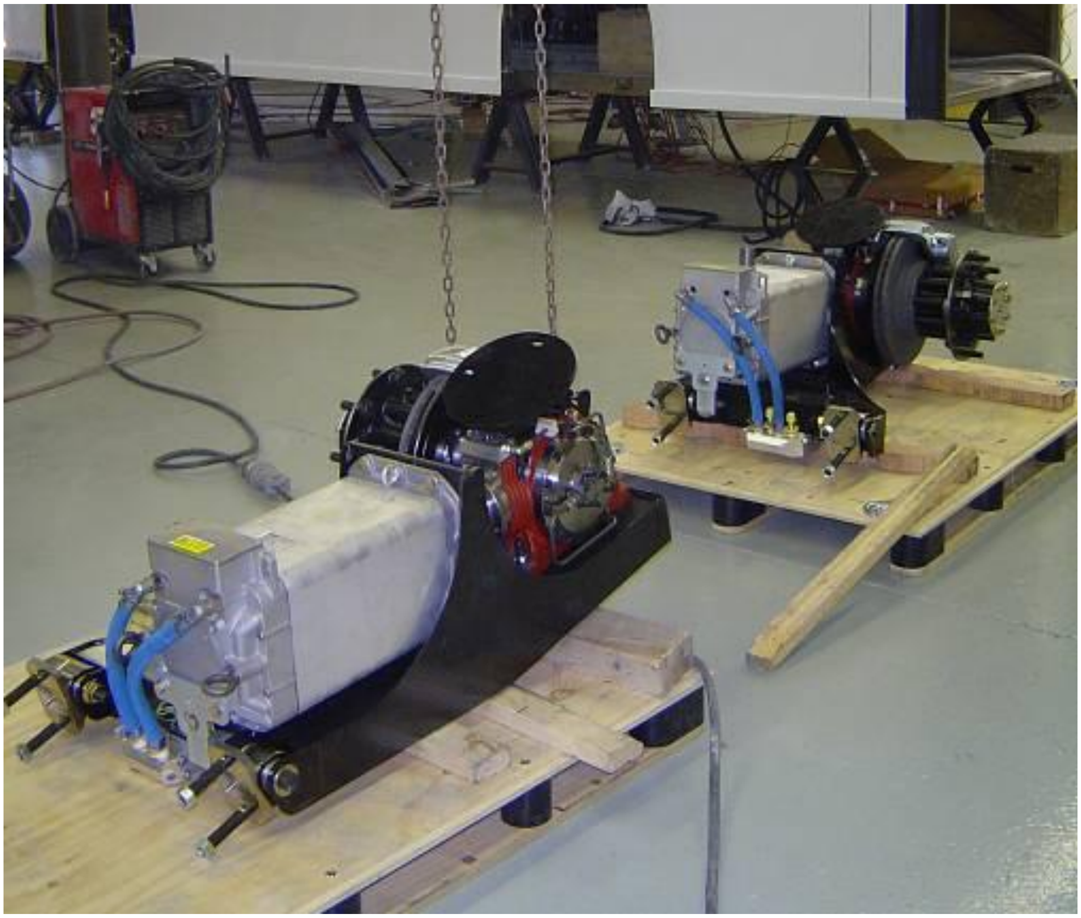

Figure 29: ArvinMeritor's QuickSider™ Swing Arm Electric Drive Units

8.2. Design of Auxiliary Systems

ArvinMeritor performed the original auxiliary power and energy calculations. In cooperation with Unicell, ArvinMeritor chose to use a 600 VDC to 220 VAC 3 phase inverter for the auxiliary system. The 12 VDC and 24 VDC systems were fed from 1400 W converters on this 220 VAC bus. The air system and steering pump were driven from a 5 HP 220 VAC 3 phase motor also driven by this auxiliary bus.

8.3. Foundation / Regenerative Brake Integration

The design targeted highest possible regenerative brake energy capture. The ArvinMeritor controller was programmed to feed up to the maximum allowable power back to the Zebra batteries. Up to 100 kW can be absorbed. To achieve this, Unicell designed a dual mode brake pedal that allowed 100 percent regeneration to be reached before the foundation brakes were engaged.

9. Assessment / Achievements

Through to the fall of 2006, the development of the QuickSider™ prototype proceeded with only minor deviations from plan. Although there were several design iterations, many technical challenges to overcome, and numerous improvements as the design progressed, there were no radical departures from the initial concept developed in 2003.

At the time of writing, the prototype vehicle has been tested by Environment Canada on its dynamometer, has been demonstrated to senior management at Purolator and ArvinMeritor, and has completed its compliance and handling testing at PMG. All those who have evaluated the QuickSider™ so far have been impressed. The vehicle accelerates, brakes and handles very well. No unsafe resonances or deflections have been detected anywhere in the structure. Its overall energy efficiency, even in its initial untuned state, is 50 percent, much higher than a conventional vehicle's 11 percent, though short of the 75 percent target. Identifiable, realistic improvements in the regenerative braking system, batteries and drive train should enable 75 percent energy efficiency in the next generation vehicle. The ZEV range of the vehicle, according to the dynamometer tests, is 130 km, just over the target 120 km. Its aerodynamic drag is less than half that of a conventional vehicle. Its appearance is dramatic, and very attractive to most, connoting energy efficiency and low environmental impact. Of greatest importance to potential users, its safety and productivity features deliver tangible benefits.

Many challenges remain, the largest of which is that the estimated production cost of the vehicle is still very high compared to that of a conventional vehicle. This substantial extra cost must be justified by benefits to the customer. It remains to be proven that this can be done and that the product is commercially viable.

10. Conclusions

The work to date confirms that the QuickSider™ will be a substantial improvement over conventional urban delivery vehicles in terms of its practical utility, energy efficiency and environmental impacts. Unicell is confident that the remainder of the test program will continue to prove the design to be sound and to confirm its operational, safety and environmental benefits.

The benefits provided by the QuickSider™ must be significant enough to justify the substantial premium that customers will have to pay for the product. Unicell will work with Purolator to complete a rigorous cost-benefit analysis of the QuickSider™ in Purolator's operations.

Unicell and its partners intend to proceed with the development and testing of the QuickSider™ prototype, and with their efforts, reduce the production cost of the vehicle through improvements in its design and effective purchasing of components.

APPENDIX A

Battery System RFP Response List

Battery Engineering & Test Services

BET Services Inc.
7400 Pacific Circle
Mississauga
Ontario, L5T 2A4
Canada
tel: (905) 564 6411
fax: (905) 564 6355

Document Short Title:

Potential Sources for Advanced Battery Systems and Response Matrix to RFP

Author: C. Bland
Issue Date: October 14, 2005
Version #: 1.0
File Name: **RFP_Response List_V1_14Oct05.Doc**
Change History (Date/Changed By/Description of Change):

Potential Sources for Electric and Hybrid Electric Traction Battery Systems and Response Matrix to Request for Proposal

KEY	
Green	Supplier acknowledged Contact Information and details. RFP sent to supplier by BET.
Orange	Supplier did NOT acknowledge Contact Information and details. RFP sent to supplier by BET.
Red	No email / no response provided by supplier regarding Contact Information. RFP NOT sent by BET.
Yellow	**Response to RFP received by BET from supplier.**

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
1	**ABAT** **Advanced Battery Technologies Inc**	**PLI**	**Advanced Battery Technologies Inc** **Zhongqiang Power Tech Ltd** **Weiyou Road** **Shuangcheng** **Heilongjiang 150100** **Peoples Republic of China** **Tel: (86) 451-53118471** **Email: MingL75@yahoo.com** **Web: www.zqpt.com** **United States:** **Ming Liu** **Add:136-14 Northern Blvd Apt.8E** **Flushing NY11354 USA** **Tel:1-718-359-6866** **Fax:1-718-359-3833** **Mobile :1-917-767-0033** **E-mail:MINGL75@yahoo.com**	**7/21/05**	**None**
2	**Avestor (Quebec Hydro)**	**Li**	**Avestor** **Head Office & Research Center** **1560 de Coulomb** **Boucherville** **Quebec J4B 7Z7 Canada** **Tel: 1-877-655-3161** **or 450-655-3161** **Fax: 450-655-9297** **Email: info@avestor.com**	**7/21/05**	**None**
3	**Odet Ergué Gabéric** **BatScap (Bolloré)**	**Lithium**	**Odet Ergué Gabéric** **Marketing & Sales** **29556 Quimper Cedex 9** **France** **Contact: Laurent Bregeon** **Tel. : + 33 (0)2 98 66 78 12** **Email: laurent.bregeon@batscap.com** **Fax : + 33 (0)2 98 66 78 01** **www.batscap.com** **www.bollore.com**	**7/21/05**	**None**

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
4	**Cobasys** **Energy Conversion Devices Inc**	**NiMH** **NiMH**	**Cobasys** **3740 Lapeer Road South** **Orion** **Michigan 48359** **Tel: 248-620.5765** **Fax: 248-620-5702** **Email: rwagner@cobasys.com** **Contact: Raymond D Wagner** **Vice President, Marketing & Communications** **Ovonic Battery Company -ECD joint venture so must go through Cobasys**	**7/21/05**	**None**
5	**Eagle Picher** **Kokam (Korea)**	**Li** **Li**	**Eagle-Picher Technologies, LLC** **Ron Nowlin** – send RFP **Email: ron.nowlin@eaglepicher.com** **Greg Miller** ***Electronics Engineering Manager*** **Phone: (417) 623-8333 Ext. 102** **Mobile: (417) 850-0513** **Fax: (417) 623-0233** **E-mail: greg.miller@eaglepicher.com** **Kokam (Korea) now part of Eagle Picher**	**7/21/05**	**None**
6 NR	**East Penn**	**PbA**	**East Penn Manufacturing Company, Inc.** **Deka Road** **Lyon Station** **PA 19536 USA** **Main Tel: 610-682-6361** **Customer Service: 610-682-4231** **Fax: 610-682-4781** **Email: eastpenn@eastpenn-Deka.com**	**7/21/05**	**None**
7 NR	**Edan Technology Corporation**	**Lithium NiMH Taiwan**	**Edan** **4F, No. 49-1, Sec 3, Nan-Gang Road, Taipei** **115, Taiwan** **Tel+886-933-921679** **Tel: 886-2-55535100** **Fax: 886-2-55535188** **Sales: Hsin-Chang Lan** **Email: export@edan.com.tw** **Web: http://www.edan.com.tw**	**7/21/05**	**None**

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
8	**Electric Energy Application Technology, Inc. (EEA)**	**NiMH**	**Electric Energy Application Technology Inc. (EEA) 1F, 3 Industry E, 9Th Rd Science-Based Industrial Park Hsinchu Taiwan, R.O.C. Tel: 886-3-5630212, 37-626 222 Fax: 886-3-5630646, 37-620 151 Email: eeatech@ms24.hinet.net No. 172, Lu-Chu Rd. Tou-Fen Town Miao-Li County Taiwan, (R.O.C) 35146 Tel: +886-37-626 222 ext 215 Fax: +886-37-620 150~1**	**7/21/05**	**None**
9	**Electro Energy**	**NiMH**	**Electro Energy Inc. 30 Shelter Rock Road Danbury Connecticut CT 06810 Tel: 203-797-2699 Fax: 203-797-2697** Send RFP to ALL (4) **Martin Klein, CEO Email: bipolarbat@aol.com Paula Ralston, Operations Manager Email: pralston@electroenergyinc.com James Landi, Pilot Operations Manager Email: jlandi@electroenergyinc.com Albert Estrada, V.P. Marketing & Sales Tel: 210 863 3598 Cell/primary Email: aestrada@electroenergyinc.com Web: www.elecgtroenergyinc.com**	**7/21/05**	**Received RFP reply**
10	**Electrovaya**	**Lithium polymer**	**Electrovaya 2645 Royal Windsor Drive Mississauga Ontario Canada L5J 1K9 Tel: 905 855 4610 Ext 3094 Fax: 905 822 7953** Contact: Sorina Roman, Sales Rep **Email: sroman@electrovaya.com Toll free: 1 800 388 2865 Web: www.electrovaya.com**	**7/21/05**	**None**
11	**E-One Moli Energy (Canada) Ltd.**		**E-One Moli Energy (Canada) Ltd North American Sales Office & Production Facility 20,000 Stewart Crescent Maple Ridge British Columbia Canada V2X 9E7 Telephone: (604) 466-6654 Fax: (604) 466-6600 Web: www.molienergy.com Email: eonemoli@e-one.com.tw Chelsea Wang**	**7/21/05**	**None**

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
12	Finn EV tech Finnish Electric Vehicle Technologies Ltd	Lithium ultra cap hybrid	Finn EV tech Oy Finnish Electric Vehicle Technologies Ltd Sepänkatu 3 11710 RIIHIMÄKI Tel. / Fax. +358 19 735 705 CEO GSM +358 41 490 3771 Email: office@fevt.com Jukka Järvinen CEO Email: jukka.jarvinen@fevt.com Tel + 358 41 490 3771 Web: http://www.fevt.com/	7/21/05	None
13	GAIA LTC	Lithium ion Lithium ion	GAIA Akkumulatorenwerke GmbH Montaniastraße 17 99734 Nordhausen Germany Tel: + 49 - 36 31 - 61 67 - 0 Fax: + 49 - 36 31 - 61 67 - 16 Email: info@gaia-akku.com Web: www.gaia-akku-online.de Web: www.lithiumtech.com Lithium Technology Corporation Directed to GAIA Akku	7/21/05	None
14	GM Battery Co Ltd Guangzhou Markyn Battery Company Ltd	Li/SOCl2, Li/MnO2 and Li-ion Polymer Lithium for Evs	Guangzhou Markyn Battery Company Ltd Unit 2310, Jiner Lise Building, Block B1 Dashi Town Panyu District Guangzhou City China Neil Zeng Tel:+86-20-61906348 Fax:+86-20-61906358 Email: neilzeng@gmbattery.com Web: www.gmbattery.com	7/21/05	None
15	GP Batteries	NiMH	GP Batteries International Limited 50 Gul Crescent Singapore 629543 Tel: (65)862-2088 Fax: (65)862-3313 11235 West Bernardo Ct. San Diego California USA 92127 Tel: (858) 674-5620 Fax: (858) 674-7237 Email: Michelle-Quah@gpbatteries.com.sg Web: www.gpbatteries.com.sg	7/21/05	None

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
16	**Harding Energy Inc.**	**NiMH**	**Harding Energy Inc** **One Energy Centre** **Norton Shores** **Michigan USA 49441** **Tel: 616-798-7033** **Fax: 616-798-7044** **Tel:(800) 798-7740** **Tel:(231) 798-7033** **Fax:(231)798-7044** **Email** **customerservice@hardingenergy.com** **Web: www.hardingenergy.com**	**7/21/05**	**None**
17	**HiCharge Technology**	**various**	**HiCharge Technology** **25 Iqbal Avenue** **Singapore** **Singapore 789466** **Tel: +65 90610460** **Fax: +65 64554333** **Email: HiCharge Technology via web** **Web: http://www.hicharge.com.sg**	**No response to web enquiry. No email contact details**	**None**
18	**Hitachi Maxell**	**Lithium Ion, Lithium polymer, NiMH**	**Maxell Canada** **50 Locke Street** **Unit #2** **Concord** **Ontario L4K 5R4** **Mark Kimberley** **Tel: 905-669-8107 x 205** **Email: mkimberley@maxell.com** **www.maxellcanada.com**	**7/21/05**	**None**
19	**Hyper Battery Co**	**maybe nothing for vehicles**	**Hyper Battery Co** **China Hyper Power Battery Branch (ShenZhen) Ltd.** **3C Jinsong Building** **Shenzhen** **China** **12-107 FuLian Garden Futian Shenzhen China** **Tel: 86-755-83268545/** **86-755-83220458** **86-755-83236468** **Fax: 86-755-83221088** **Email:Sales@hyperbattery.com** **China Hyper Power (HONG KONG) Ltd.** **Room803A,8/F** **Far East Consortium bldg** **121 Dex Voeux Road** **Central,HK** **Tel: 852-21211269** **Fax: 852-21370008** **Email: Sales@hyperbattery.com** **Hyper Battery Usa Co.,Ltd** **Tel: 001-6264578422** **Email :Sales@hyperbattery.com** **Web: http://www.hyperbattery.com**	**7/21/05**	**None**

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
20	LeClanche SA		LeClanche SA 48 Avenue. de Grandson Yverdon-les-Bains Switzerland CH-1401 Tel: ++41-24-447 22 72 Fax: ++41-24-447 22 85 Email: custservice@leclanche.ch	7/21/05	None
21	LG Chemical America Inc		LG Chemical America Inc LG Twin Towers East 26th floor 20 Yeouido-dong Yeongdeungpo-gu Seoul 150-721 Korea T G Kim Email : tggreat@lgchem.com Tel:82-2-3773-6928 Fax:82-2-785-0147 or Allen Sung Email : kjsung@lgchem.com Tel:82-2-3773-7788 Fax:82-2-785-0147 Web: www.lgchem.com	7/21/05	None
22	Moltech Power Systems		Moltech Power Systems 12801 US Hwy 441 N. Alachua Florida USA 32615 Tel: 386-462-3911 Fax: 386-462-6211 Email: Web: http://www.moltech.com/	VOID Bankrupt? Not sent	None
23	NGK	NaS	NGK Insulators Ltd 2-56 Suda-cho Mizuho Nagoya 467-8530 Japan Tel: (052) 872-7171 Web: www.ngk.co.jp Email – via web	No response to web enquiry. No email contact details	None
24	Panasonic	NiMH, Lithium Ion	Panasonic Canada Inc. 5770 Amber Drive, 27 Mississauga, ON L4W 2T3 Tel: (905) 238-2236 Fax: (905) 238-2414 Pat Richards Email: prichards@ca.panasonic Web: www.panasonic.ca	7/21/05 Email not valid 2nd time	None

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
25	Peacebay Power Co Ltd	Ev battery packs	Peacebay Power Co Ltd Headquarters: No.15 Kaihua RD Huayuan Hi-Tech Industry Area Tianjin China Tel: +86-22-83711838, 83712703 Fax: +86-22-28131934 Web: http://www.peacebay.com Email:sales@peacebay.com ; hpbatt@public.tpt.tj.cn US Sales: 2631 Falcon Knoll Lane Katy TX 77494 Tel: +01-281-3954804 Fax:+01-281-3954805 Contact: Youhong Yang Email:sales@peacebay.com; youhongyang@peacebay.com	7/21/05	Received RFP reply
26	Power-Sonic Europe Limited		Power-Sonic Corporation Redwood City CA 94063 USA Email: bender@power-sonic.com Contact Bruno Ender Export Sales Manager Tel: 650-364-5001 Fax: 650-366-3662 Web: www.power-sonic.com	7/21/05	No bid Bruno Ender only lead acid
27	SAFT	NiMH	Saft Headquarters 12, rue Sadi Carnot 93170 Bagnolet - France Tel.: +33 (0)1 49 93 19 18 Fax: +33 (0)1 49 93 19 50 Email: via web Web http://www.saftbatteries.com	No response to web enquiry. No email contact details	None
28	Sanyo	NiMH	SANYO Batteries & Accessories 2055 Sanyo Ave. San Diego California USA 92154 Tel: (619) 661-4888 Fax: (619) 661-6743 Email: battery@sci.sanyo.com Email: yfarrell@sanyo.com Web: http://www.sanyobatteries.com	No response Ford?	None
29	Sanyo GS Co Ltd GS-Melcotec Co Ltd	Lithium Ion	Sanyo GS Co Ltd 18952 MacArthur Boulevard Suite 470 Irvine California 92612 USA Tel: (877) 476-8872 Web: www.sanyo-gs.com Email: info@sygsusa.com	7/21/05	None

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
30	Sony		Sony of Canada Ltd. 115 Gordon Baker Road Toronto Ontario M2H 3R6 Canada. Tel: 416-499-1414 or 416-495-3708 (DID) Fax: 416-495-2250 Sumant Sharma Consumer Media, RME E-mail: sumant_sharma@sony.ca Web: http://www.sony.com/	7/21/05	None
31	Suppo	NiMH	Suppo Hong Kong Suppo Battery Co Ltd Room 1201, Unit 1, 12/F., Ricky Centre, No. 36 Chong Yip Street Kwun Tong Kowloon, Hong Kong, China Tel: 852-2802 4682 Fax:852- 2824 1519 Email: info@suppo.com Web: http://www.suppo.com	7/21/05	None
32	Supreme Battery		Supreme Battery 185 Mountain Top Road,Waleska, GA, 30183 Tel: 770-655-9769 Or 800-906-0603 Fax: 770-704-9251 Email: Info@supremebattery.net Web: www.supremebattery.net	7/21/05	None
33	Thunder Sky	Lithium	Thunder Sky Battery Ltd. Langshan 2nd Road(South) High-Tech Industrial Park(North) Nanshan Dist. Shenzhen P.R.C 518057 Tel:+86 755 86026789 Fax:+86 755 86026678 Email: thunder@thunder-sky.com Contact: Winston Chung (CTO) Web: http://www.thunder-sky.com	7/21/05	Received RFP reply
34	Toshiba America Inc		Toshiba America, Inc. 1251 Avenue of the Americas Suite 4110 New York NY 10020 Tel: 1-800-316-0920 Email: - via web Web: www.toshiba.com	No response to web enquiry. No email contact details	None
35	U&C Batteries Private Limited	NiMH	U&C Batteries Private Limited #7-169, Plot 46, HAL Employees' Colony Old Bowenpally Secunderabad AP INDIA 500011 Tel: 0091-40-27757161 Fax: 0091-40-27755761 Email: pcmrao@ucbatteries.com Web: ucbatteries.com	7/21/05	None

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
36	Ultralife	Lithium	Ultralife Batteries Inc 2000 Technology Parkway Newark NY 14513 USA Tel: (315) 332-7100 Fax: (315) 331-7800 Mr. John McCusker - RFP contact Northeast Region Sales manager Email: jmccusker@ulbi.com Web: http://www.ultralifebatteries.com	7/21/05	No Bid Outside product range
37	Unipower		Unipower 1216 West 96th Street Minneapolis Minnesota 55431 USA Tel: 800-542-6998 Fax: 612-884-1726 Email: ronolsten@unipower.com Web: www.unipower.com	7/21/05	None
38	Valence Technology	Phosphate Lithium Ion	Valence Technology 6504 Bridge Point Parkway Suite 415 Austin Texas 78730 Marc Kohler Tel: 512 527 2900 Email: marc.kohler@valence.com Web: www.valence.com	7/21/05	Received RFP reply
39	Varta	NiMH	VARTA Automotive Johnson Controls Batteries European Headquarters VB Autobatterie GmbH Plant Hannover 30417 Hanover Germany Tel: +49 5 11 9 75 01 Fax: + 49 5 11 9 75 10 10 Email:via web Web: www.varta-automotive.com Daimlerstrasse 1, Elwangen, Germany D-73479 Telephone: 0049 7961921627	No response to web enquiry. No email contact details	None
40	Wavecrest	NiMH Lithium	Wavecrest 13680 NW 104th Terrace Alachua FL 32615 Tel: (386) 418-3678 Fax: (386) 418-2238 Rick Eagle, Director Web: http://www.wavecrestlabs.com/ Email: rick.eagle@wavecrestlabs.com	7/21/05	Declined to quote

	Potential Source	Electro-chemistry	Contact Information	Package Sent (Date)	Response Received
41	**Worley Parsons**	**vehicle battery packs Kokam Lithium**	**Worley Parsons** **Level 7** **116 Miller St** **North Sydney** **NSW 2060** **Tel: (02) 8923 6866** **Fax: (02) 8923 6877** **Email: wpnews@worleyparsons** **Web: http://www.worley.com.au**	**7/21/05**	**None**
42	**ReVolt Technology AS**		**ReVolt Technology AS** **Innherredsveien 7** **7014 Trondheim** **Norway** **Nils Kristian Nakstad** **Email: nkn@revolttechnology.no**	**7/21/05**	**None**

APPENDIX B

Battery System RFP Response Evaluation

Ranking of RFP Responses for
Statement of Requirements for a Traction Battery System for the Unicell Quicksider Vehicle
October 14, 2005

Some notable RFP non-respondants: Cobasys; Electrovaya; Varta; SAFT

*Importance based on Unicell Quicksider needs:
Low = Indicator of past record; R&D resources; Technical foundation
Med = Commercial record; Helpful to (Quicksider) commercialization
High = Key to successful (Quicksider) commercialization

					MES-DEA: ZEBRA/NaNiCl (BET Series B4Z)			Thundersky: Li			Electroenergy: NiMH			Peacebay: NiMH			Valence: Lithium Ion (Phosphate)		
					TOTAL SCORE:	67	(out of 83)	TOTAL SCORE:	61	(out of 83)	TOTAL SCORE:	59	(out of 83)	TOTAL SCORE:	48	(out of 83)	TOTAL SCORE:	45	(out of 83)
					RANK:	1	(out of 5)	RANK:	2	(out of 5)	RANK:	3	(out of 5)	RANK:	4	(out of 5)	RANK:	5	(out of 5)
	Requirement	**Unit**	**Importance* of Each Requirement** *Low = 1 Med = 2 High = 3*	**Target Value for Battery System** *(incl. all balance of battery system hardware, etc.)*	**Actual Value of Candidate Battery System** *(incl. all balance of battery system hardware, etc.)*	**Meets Target Value?** *YES scores 1, NO scores 0*	**Score for Candidate Battery System** *"Importance" x "Meets Target"*	**Actual Value of Candidate Battery System** *(incl. all balance of battery system hardware, etc.)*	**Meets Target Value?** *YES scores 1, NO scores 0*	**Score for Candidate Battery System** *"Importance" x "Meets Target"*	**Actual Value of Candidate Battery System** *(incl. all balance of battery system hardware, etc.)*	**Meets Target Value?** *YES scores 1, NO scores 0*	**Score for Candidate Battery System** *"Importance" x "Meets Target"*	**Actual Value of Candidate Battery System** *(incl. all balance of battery system hardware, etc.)*	**Meets Target Value?** *YES scores 1, NO scores 0*	**Score for Candidate Battery System** *"Importance" x "Meets Target"*	**Actual Value of Candidate Battery System** *(incl. all balance of battery system hardware, etc.)*	**Meets Target Value?** *YES scores 1, NO scores 0*	**Score for Candidate Battery System** *"Importance" x "Meets Target"*
1	Electrochemistry	--	--	NiMH, Li, etc	Sodium Nickel Chloride			Lithium			Nickel Metal Hydride			Nickel Metal Hydride			Lithium Ion (Phosphate)		
2	Time in Development for traction batteries	years	1	≥ 15	> 25	YES	1	8	no	0	13	no	0	8	no	0	16	YES	1
3	Time in Production of traction batteries	years	2	≥ 2	> 8	YES	2	8	YES	2	0	no	0	> 6	YES	2	1	no	0
4	kWh of traction batteries produced	kWh	1	>1000	>1000	YES	1	"YES"	YES	1	N/A	no	0	>1000	YES	1	>1000	YES	1
5	Initial Cost (for kWh of Energy in # 11)	US$	3	≤ $40,000	$60,000	no	0		no response	0	$40,000 / $80,000	no for "Option 2"	0	USD 450 - 590	YES (Assume $/kWh)	3	$82.5K	no	0
6	Battery Lease Option Available		1	Yes	YES	YES	1	"YES"	YES	1	No	no	0	Yes	YES	1	no*	no	0
7	Warranty (including balance of battery system)	years	3	≥ 1	≥ 1	YES	3	"YES"	YES	3	1	YES	3	≥2	YES	3	≥1	YES	3
8	Expected Nameplate Cycle Life (to 100% DOD)	cycles	2	≥ 2000	1000 - 2500	YES	2	500	no	0	500 / 2000	YES	2	>1200	no	0	> 1000	no	0
9	Expected Nameplate Cycle Life (to 70% DOD)	cycles	3	≥ 5000	1000 - 2500	no	0	3000	no	0	1000 / 5000	YES	3	>6000	YES	3	> 2000	no	0
10	Expected Calendar Life	years	3	≥ 10	> 12 yrs	YES	3	8	no	0	10	YES	3	>8	no	0	> 10	YES	3
11	Energy (≤ 2 h Discharge)	kWh	2	≥ 80	80	YES	2	"YES"	YES	2	80 (92/39)	YES	2	> 80	YES	2	80	YES	2
12	System Weight (including charging, cooling, heating & control systems) for kWh of Energy claimed in # 11 above	kg	3	≤ 900	828	YES	3	"no"	no	0	1900 / 2800	no	0	< 880	YES	3	825	YES	3
16	System (including charging, cooling, heating & control systems) Gravimetric Energy Density (≤ 2 h Discharge)	Wh/kg	3	≥ 120	96	no	0	"YES"	YES	3	48 / 49	no	0	> 65	no	0	97	no	0
17	Energy Density (system including charging, cooling, heating and control systems) (≤ 2 h Discharge)	Wh/l	3	≥ 200	> 500	YES	3	"YES"	YES	3	150 / 150	YES	3	> 200	YES	3	132	no	0
18	Peak Discharge Power (≥30 s)	kW	3	≥ 160	144	no	0	"YES"	YES	3	160 / 240	YES	3	>250	YES	3	>160	YES	3
19	Peak Regenerative Power (≥30 s)	kW	3	≥ 160	>160	YES	3	"YES"	YES	3	160 / 240	YES	3	> 160	YES	3	160	YES	3
20	Peak System (system including charging, cooling, heating and control systems) Gravimetric Power Density (>30s)	W/kg	3	≥ 200	172	no	0	"YES"	YES	3	85 / 85	no	0		no response	0	194	no	0
21	Peak System (system including charging, cooling, heating and control systems) Power Density (≥30s)	W/l	3	≥ 300	> 300	YES	3	"YES"	YES	3	260 / 260	no	0	400	YES	3	264	no	0
22	Nominal Operating Voltage	V	2	550 - 650	620	YES	2	"YES"	YES	2	580	YES	2		no response	0	614	YES	2
23	Minimum Operating Voltage	V	2	≥ 400	408	YES	2	"YES"	YES	2	500	YES	2	> 300	no	0	480	YES	2
24	Effects of Outside Temperature (-40°C to +50°C)		2	None	None	YES	2	"YES"	YES	2	None	YES	2		no response	0	-20C to +50C	YES	2
25	"Memory Effect"		2	None	None	YES	2	"YES"	YES	2	None	YES	2		no response	0	None	YES	2
26	Self discharge rate @ RT & 100% DOD	Wh/24h	2	0	0	YES	2	"YES"	YES	2	Up to 15% at 100% SOC	no	0	0.3	no	0	2.8	no	0
27	Freeze/Thaw Cycling, if applicable, e.g. 'hot' electrochemistries	cycles	2	≥ 10	No Limit	YES	2	"YES"	YES	2	tbd	no	0	> 10	YES	2	N/A	YES	2
28	Vibration		2	Typical passenger vehicle duty	Typical passenger vehicle duty	YES	2	"YES"	YES	2	Typical passenger vehicle duty	YES	2		no response	0	Typical passenger vehicle duty	YES	2
29	Requirement for Recharge from Grid (to 0% DOD)		2	≤ Nightly	Nightly	YES	2	"YES"	YES	2	Nightly	YES	2		no response	0	Nightly	YES	2
30	Cell Failure Tolerance	%	2	Operation continues to 5% cell failures	Operation continues to 5% cell failures	YES	2	"no"	no	0	50	YES	2	Operation continues to 5% cell failures	YES	2		no response	0

31	Minimum thermal runaway temperature	^{o}C	2	>600	>600	YES	2	"no"	no	0	N/A	YES	2		no response	0	N/A	YES	2
32	Maintenance Issues		2	None, outside of module replacement	None	YES	2	"no"	no	0	None	YES	2		no response	0	None, outside of module replacement	YES	2
33	Recyclability • Hazardous materials • Toxic materials • Benignly disposable		3	Excellent: • No hazardous materials • No toxic materials • Remainder benignly disposable	Excellent	YES	3	"YES"	YES	3	Excellent	YES	3	Excellent	YES	3	Excellent	YES	3
34	Safety		3	Excellent • No gassing, • no acids, • no thermal runaway possible	Excellent	YES	3	"YES"	YES	3	Excellent	YES	3	Excellent	YES	3	Could gas if overcharged, could leak electrolyte if crushed or overcharged no thermal runaway possible	no	0
35	Electrical Safety		3	Passive safety with 'finger safe' access features and IP67 level sealing	Passive Safety	YES	3	"YES"	YES	3	Safe	YES	3	Passive Safety	YES	3	application engineering by your customer is responsible for sealing and passive safety.	no	0
36	Conformance to major safety standards		3	• SAE, CMVSS/FMVSS, • CSA, • UL, • Manual battery disconnect device incorporated • High potential terminals safeguarded	Very Safe	YES	3	"YES"	YES	3	All Can be satisfied	YES	3	Very Safe	YES	3		no response	0
37	Thermal management		1	• Is thermal management fully integrated if required	Thermal management fully integrated	YES	1	"no"	no	0	Yes	YES	1	thermal management fully integrated if required	YES	1	Thermal management would have to be added if required	no	0
38	Slow charge capability (include all hardware claimed in #14 plus any power management hardware required)		1	• Integral part of system	Optional part of system components	YES	1	"YES"	YES	1	Yes	YES	1	Integral part of system	YES	1	charging is an add-on either provided by a third party or the customer	no	0
39	Fast Charge capability (be sure to include components claimed in # 14 plus any power management hardware required)		1	• Charge time for 20% SOC to 80% SOC ≤ 1 hour • Integral part of system	Fast Charge capability, but not fully integrated	no	0	"YES"	YES	1	1 - 2 hour charge	YES	1		no response	0	Charge time for 20% SOC to 80% SOC < 1 hour Integral part of system	YES	1
40	Diagnostics capability		1	Integral part of system for troubleshooting	Integral part of system for troubleshooting	YES	1	"YES"	YES	1	Can be Incorporated	YES	1		no response	0	Integral part of system for troubleshooting	YES	1
41	Single Battery or Module Control & Management (be sure to include mass and components claimed in # 14)		2	Hardware & software fully integrated or not required; CAN protocol required	Hardware & software fully integrated; With CAN	YES	2	"YES"	YES	2	Control system fully integrated	YES	2		no response	0	Hardware & software fully integrated or not required; MODbus protocol required	YES	2
42	Battery network control & management (be sure to include mass and components claimed in # 14)		1	Hardware & software fully integrated or not required; CAN protocol required	Hardware & software fully integrated; With CAN	YES	1	"YES"	YES	1	Control system fully integrated	YES	1		no response	0	Hardware & software fully integrated or not required; CAN protocol required	YES	1