DOE Vehicle Technologies Office Program Record	
Record # 20-01	Date: December 31, 2019
Title: Vehicle Lightweighting Program Progress Status - 2019	
Originators: David Gotthold, Sarah Kleinbaum, Felix Wu, Jerry Gibbs, Gurpreet Singh	
Peer Reviewers: USDRIVE Materials Tech Team	
Approved by:	Date:

Advanced lightweight materials are essential for improving the fuel economy of modern automobiles while maintaining safety and performance. A 10% reduction in vehicle weight can result in a 6%-8% fuel economy improvement for traditional internal combustion vehicles since it takes less energy to accelerate a lighter object than a heavier one [1]. Using lightweight materials in hybrid electric, plug-in hybrid electric, and electric vehicles can offset the weight of power systems such as batteries and electric motors, improving the efficiency and increasing their all-electric range. Alternatively, the use of lightweight materials could allow for the use of a smaller and lower cost battery while keeping the all-electric range of plug-in vehicles constant.

The Materials Technology research portfolio seeks to enable and demonstrate a 25% weight reduction of the vehicle glider, as compared to a 2015 baseline (Appendix A), at less than \$11/kg-saved (\$5/lb-saved) by 2025. This document provides a summary of progress in achieving the 2025 target.

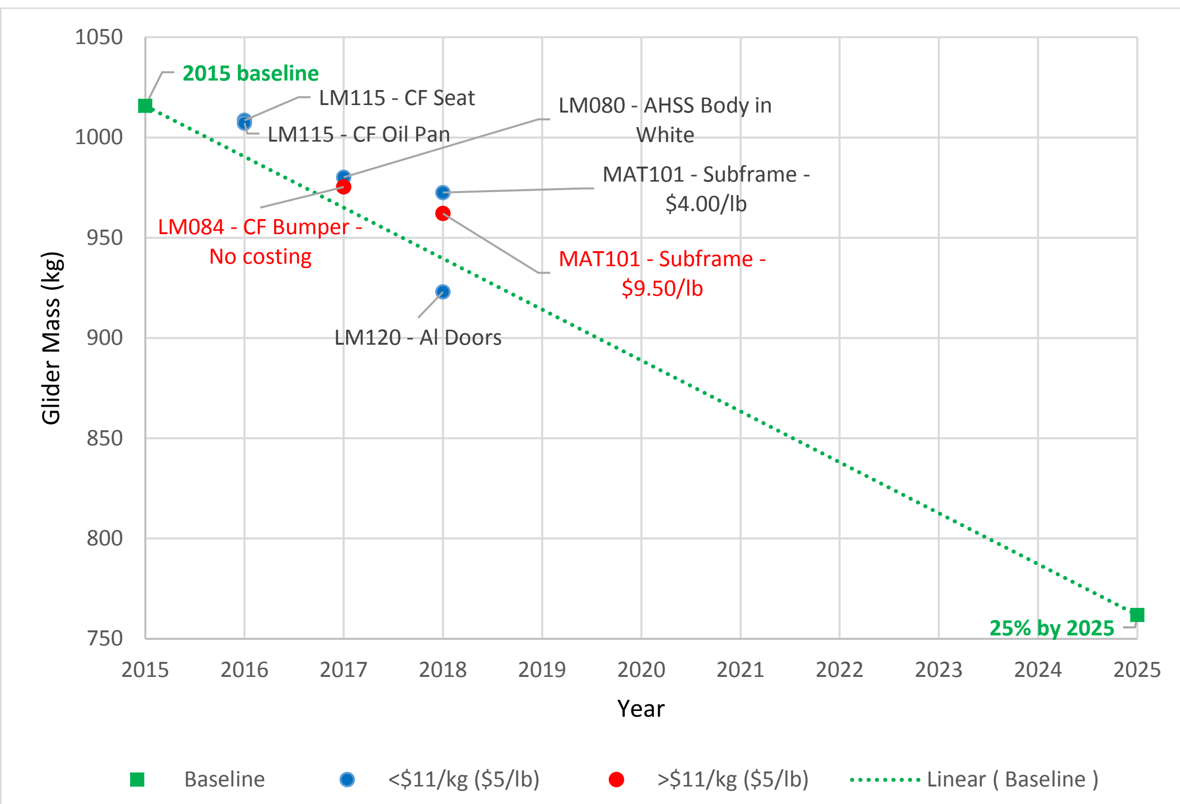

Figure 1: Chart showing cumulative mass reduction as a function of year for selected component demonstration projects that met the DOE cost target. Certain projects that did not perform a cost analysis or did not meet the cost targets are shown in red for reference but are not included in the cumulative mass reduction calculations.

For 2016-2019, Materials Technology funded research projects have demonstrated a 92.8 kg (9.14%) weight reduction of the vehicle glider at the target costs. This is actually the savings through 2018, as there were no component demonstration projects that ended in 2019. In addition to the projects referenced here, Materials Technology supports a multitude of enabling research efforts on material development, process development, joining, and modeling which form the foundation on which the demonstration projects are built. The weight reductions calculated here are based on the research program and have not necessarily transitioned to industrial production. In general, the projects included in this document demonstrate a final Technology Readiness Level (TRL) of 4-6 – laboratory demonstration of a component to prototype demonstration in a relevant environment [2]. This is the first release of this record.

Specific progress points included in this report are:

- LM115 - Demonstration of injection molded long carbon fiber composites for oil pan and seat back, with savings of 1.4 and 7.25 kg (1.81 x 4 seats) respectively with a cost of less than $4.4/kg saved.
- LM080 - Modeling of an AHSS based body in white, showing a savings of ~30% (27 kg) for an expected cost of between $0.70 and $2.77/kg saved.
- LM120 – Demonstration of door lightweighting that addresses not only the structural components, but the complete bill of materials, with a projected total savings of 49.6 kg (109.1lbs) per vehicle.
- MAT101 – Modeling of lightweight subframes via various metal/composite designs. A steel intensive design (79% steel/21% CF composite) achieved both the weight savings and cost target. For reference, the primarily composite design was able to achieve larger weight savings but was well above the cost target.

Project Summaries

LM115 Predictive Engineering Tools for Injection Molded Long Carbon Fiber Thermoplastics

Component	Project Reference Material & Mass	Demonstrated Material & Mass	Demonstrated Mass Saved	Cost for Mass Savings
Seat back	Cast Al, 3.56 kg	Injection molded CF reinforced PA66 polymer, 1.75 kg	1.81 kg (7.24 kg / vehicle)	$3.48/kg ($1.58/lb)
Oil Pan	Cast Al, 2.97 kg	Injection Molded CF reinforced PA66 polymer, 1.6 kg	1.4 kg	$4.81/kg ($2.18/lb)

PI: Vlastimil Kunc (Oak Ridge National Laboratory)
Project Team: ORNL, Ford, Moldex3D NA, BASF, PlastiComp, VPI, University of Illinois

Project Objective / Summary:
The overall goal of this project was to develop and validate the computational tools needed for predictive modeling of the fiber length and orientation for injection molding of long carbon fiber reinforced thermoplastics. Various samples were molded, and fiber length and orientation were characterized to improve the model performance in both Molex3D and Moldflow software. In order to demonstrate the functionality of the models, a complex seatback structure was modeled and fabricated to measure the accuracy of the fiber orientation modeling [3]. In parallel, Ford and BASF investigated the potential production of an oil pan using the models developed in this project [4]. Based on the modeled component masses, the estimated production costs were calculated.

				English Units
Number of Parts Per Vehicle				4
Mass Saved Per Part				3.98 lb
Cost Penalty Per Part		$6.83		$6.29
Total Mass Saved Per Vehicle		3.12 lb		15.92 lb
Cost Penalty Per Vehicle		$6.83		$25.16
Total Vehicle Cost Penalty Per Unit Mass		$3.10/lb		$1.58/lb

Table 1: Costs and parts for oil pan and seat back [3]

Cost and weight savings analysis:

The project reference materials selected by this project are cast Al parts and are reasonable for light weight applications, but they differ from the baseline materials used in the DOE 2015 baseline composite vehicle.

For the seatback, the DOE baseline material is steel, and the average mass is 4.5 kg (9.9lb). Using this baseline as a reference would provide a larger weight savings, (approximately 1 kg/seat) but also a larger cost penalty. The magnitude of the cost penalty delta is difficult to calculate but is unlikely to be above the DOE target of $11/kg. The overall cost analysis for the seat backs are "rough estimates at best" [3] as the tooling and manufacturing costs of the cast Al reference component were estimates.

For the oil pan, the project reference material provided is also a die cast aluminum part with a mass of 2.97 kg, which is a component that Ford Motor Company (a team member on the project) was actually producing so the estimated production costs are more substantiated. Cast Al is also the same material and a similar mass to the DOE baseline vehicle, so provides a good comparison.

The cost of the carbon fiber is not broken out separately, but the composite, consisting of PA66 with 40% carbon fiber has a total cost of $17.63/kg, compared to the Al cost of $6.90/kg used in the cost model. The final part cost is heavily dependent on the material cost and therefore continued reduction in carbon fiber costs will benefit these projects.

As of 2019, carbon fiber based oil pans are in industrial demonstration while the seat backs are still in development.

LM080 Integrated Computational Materials Engineering Approach to Development of Lightweight 3GAHSS Vehicle Assembly

Component	Project Reference Material & Mass	Demonstrated Material & Mass	Demonstrated Mass Saved	Cost for Mass Savings
Body in white side structure	AHSS, ~94 kg	3GAHSS, 67.5 kg	~27 kg	$0.70-2.77/kg ($0.32-1.26/lb)

PI: Louis Hector (GM), Jody Hall (Auto/Steel Partnership)
Team: FCA US LLS, Ford Motor Company, General Motors Company, ArcelorMittal, AK Steel Corporation, Nucor Steel Corporation, EDAG, LSTC, Brown U., Clemson U., Colorado School of Mines, PNNL Ohio State U., U. Illinois Urbana-Champaign, Auto/Steel Partnership, USAMP

Project Objective / Summary:

The overall objective of this project was to integrate multiple material models across different length scales to be able to reduce the time needed to develop and use new third generation advanced high strength steel (3GAHSS). The project developed a 3GAHSS ICME model to identify new alloys that have the potential to replace AHSS, one with high strength and exceptional ductility (CMAT Med Mn 2.1) and one with exceptional strength and high ductility (CMAT Q&P 2.2). Extensive material and formability testing was performed to build the material cards necessary for structural modeling.   However, the full structures were not made or tested, so other potential challenges in forming and joining were not addressed. The final structure had both fewer components (reduced from 46 to 28) and thinner gauge materials and had an estimated 30% weight reduction [5].

Cost and weight savings analysis:

The DOE reference vehicle does not break down the BIW into sub-structures, but instead only has a complete structure mass of 329 kg. The structure is steel, but the specific types of steel are not specified. The referenced structure proposed by the team was an AHSS structure from a 2008 model year sedan, and includes both sides of the vehicle, but does not include the subframe, floor, roof and cross members. It is reasonable that these remaining components would account for the remaining baseline mass of 235 kg (329 kg BIW – 94 kg side structure). Figure 2 shows the side-structure assembly with the various components that were optimized.

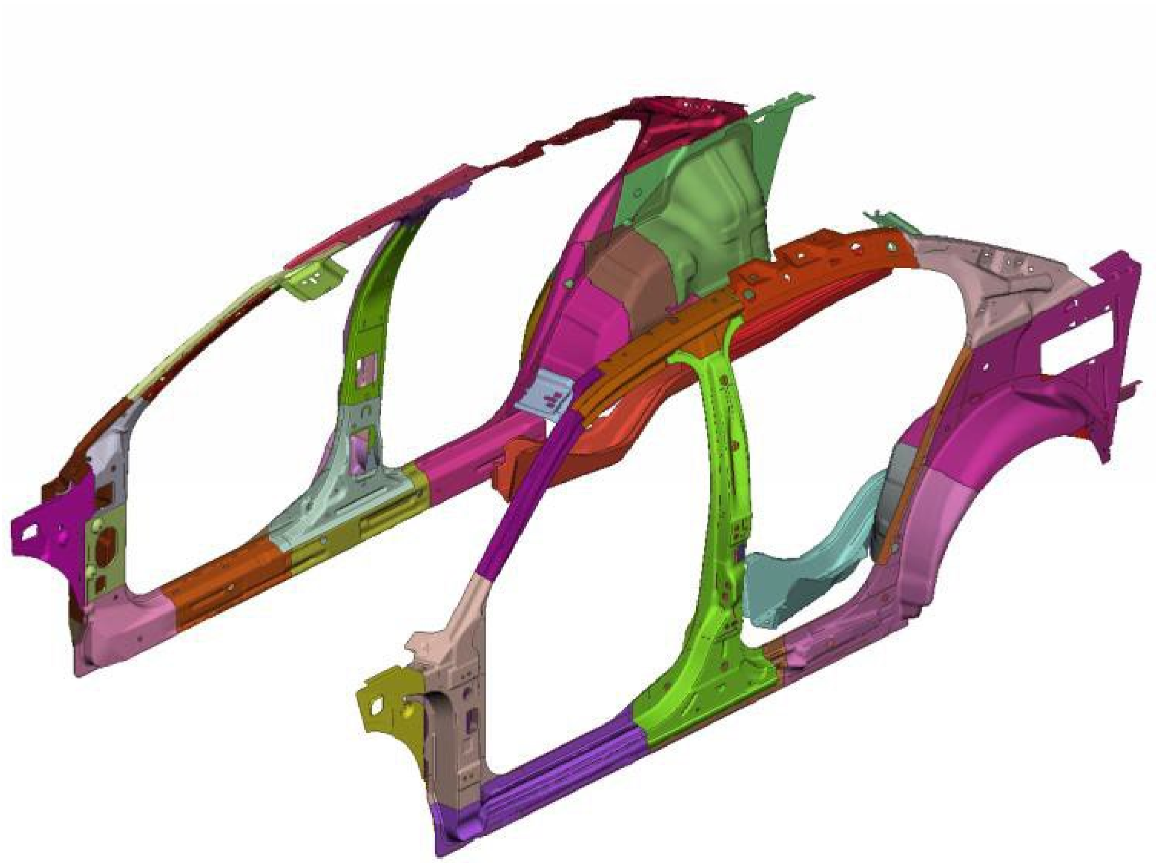

Figure 2: Side structure assembly [6]

As there was no 3GAHSS in volume production, the project estimated the cost based on existing steels. For the High Strength, Exceptional Ductility TRIP steel, costs were extrapolated from lower strength commercially available TRIP steels. For the Exceptional Strength, High Ductility QP steel, there was not a commercially available comparison, so complex phase steel prices were used for reference.

LM084 Validation of Material Models for Crash Simulation of Automotive Carbon Fiber Composites Structures

Component	Project Reference Material & Mass	Demonstrated Material & Mass	Demonstrated Mass Saved	Cost for Mass Savings
Bumper assembly	Steel, 10.7 kg	CFRP, 5.85 kg	4.85 kg	Not calculated

PI: Omar Faruque (Ford), Anthony Coppola (General Motors)
Team: USAMP (GM, Ford, FCA Group), Northwestern University, University of Michigan, Wayne State University

Project Objective / Summary:

This project designed and built a carbon fiber reinforced polymer (CFRP) bumper assembly, including the crush cans. The goal of this project was to demonstrate the feasibility of design modeling to accurately predict the behavior of CFRP during crash conditions.

Because the nature of the project was to demonstrate crash simulations, there was no cost modeling performed. The various components were designed to simplify manufacturing and work with high volume manufacturing, however significant work remains on the assembly process including understanding draping of the woven fabrics and optimizing the fiber orientation [7]. This structure, as it is almost 100% CFRP, will benefit from lowering the cost of carbon fiber.

LM120 Ultralight Door Design, Manufacturing and Demonstration Project

Component	Project Reference Material & Mass	Demonstrated Material & Mass	Demonstrated Mass Saved	Cost for Mass Savings
Door (Front)	Steel intensive, 38 kg	Al intensive 22.9 kg	15.2 kg (30.4 kg total)	\$6.18/kg (\$2.81/lb)
Door (Rear)	Steel intensive, 25.8 kg	Al intensive, 16.2 kg	9.6 kg (19.2 kg total)	

PI: Tim Skszek (Magna International)
Team: Vehma International, Magna International, Magna Closures, FCA US LLC, Grupo Antolin NA

Project Objective / Summary:

This project developed and demonstrated a full lightweight door system, including an aluminum frame, lightweight glass, electric latch and a design that enables a simplified interior trim. In this project, multiple full doors were assembled and tested to demonstrate crash performance, long term corrosion, noise vibration and harshness (NVH), and durability using full automotive performance testing.

Cost and weight savings analysis:

For this project, the baseline chosen was a 2016 Chrysler 200C sedan door, with similar design to the DOE 2015 composite baseline. For the front doors, the baseline is 38.0 kg which is 30% heavier than the DOE baseline average of 28.8 kg, but it does match the DOE data for the 200C that is in the baseline. For the rear doors, the baseline is 25.8 kg, which is nearly the same as the DOE 25.11 kg. Table 2 shows the breakdown of the weights for both the front and rear doors.

Auto parts (door components/subassembly)	**Front door**				**Rear door**			
	Baseline	**Ultralight**	**Mass reduction**		**Baseline**	**Ultralight**	**Mass reduction**	
	(kg)	**(kg)**	**(kg)**	**(%)**	**(kg)**	**(kg)**	**(kg)**	**(%)**
1. DIW	16.95	9.32	7.6	45	12.54	6.89	5.6	45
2. Door module	2.85	1.8	1	37	2.45	1.55	0.9	37
3. Interior trim	4.31	2.65	1.7	38	1.35	0.83	0.5	38
4. Glass	4.12	2.15	2	48	2.85	1.49	1.4	48
5. Mirror	1.42	1.01	0.4	29	Not applicable			
6. Seals	2.18	1.99	0.2	8	1.71	1.56	0.1	8
7. Exterior handle	0.65	0.12	0.5	82	0.46	0.08	0.4	82
8. Latch	0.81	0.5	0.3	39	0.82	0.5	0.3	39
9. Speaker	0.96	0.5	0.5	48	0.33	0.17	0.2	48
10. Electrical components	1.27	1.07	0.2	16	0.9	0.76	0.1	16
11. COP	0.66	0.66	0	0	0.62	0.62	0	0
12. Other	0.46	0.23	0.2	49	0.43	0.43	0	0
13. Fasteners	0.46	0.41	0.1	12	0.43	0.43	0	0
14. Adhesives	0.95	0.45	0.5	52	0.89	0.89	0	0
Total door	38	22.9	15.2	40	25.8	16.2	9.6	37

Table 2: Weight reduction achieved by component or subsystem [8]

As the project selected baselines are similar to the DOE baseline (and in fact are based on one of the 16 vehicles in the baseline) the proposed savings are taken as presented. The cost analysis was not presented in detail but was performed using industry standard methods by automotive industry team members and is based on an existing production door. The cost savings varied over the course of the project, but the $6.18/kg value selected was presented in the program final report [9].

MAT101 Integrated Computational Materials Engineering (ICME) Development of Carbon Fiber Composites for Lightweight Vehicles

Component	Project Reference Material & Mass	Demonstrated Material & Mass	Demonstrated Mass Saved	Cost for Mass Savings
Subframe (within cost target)	Steel, 57.4 kg	79% steel, 21% CFRP, 49.8 kg	7.6 kg (30%)	$8.82/kg ($4.01/lb)
Subframe (lightest)	Steel, 57.4 kg	88% CFRP, 12% steel, 46.4 kg	10.5 kg (41%)	$19.58/kg ($8.90/lb)

PI: Xuming Su, David Wagner (Ford Motor Company)

Team: Ford Motor Company, Dow Chemical, Northwestern University, NIST/University of Maryland

Project Objective / Summary:

The team developed the ICME tools to design a hybrid metal and composite subframe assembly for a light duty vehicle. The project evaluated performance via CAE model, but no physical testing was conducted so potential additional challenges in manufacturing or assembly were not studied. To provide inputs for the ICME models, extensive testing was done of the composite materials to measure the material parameters. These were then combined with existing models and data on steel and aluminum alloys to develop full structural models.

Cost and weight savings analysis:

For this project, the baseline was the engine subframe of an unspecified light duty sedan with an all steel construction. As the DOE baseline does not break out the subframe, it is difficult to compare, but the vehicle type and material construction is consistent with the target baseline. With Ford providing the model, it is reasonable to assume the structure is similar to other Ford sedans. While the actual frame was not fabricated, several different designs were modeled, and the costs calculated from those designs.

> *"The model estimates the variable cost based on the weight of the materials used in the sub-frame. The estimate uses weighted ratios of the materials coupled with our internal Ford material and manufacturing costs for stamped steel, Al, and CF composite subframes as the reference points." [10]*

Figure 3 shows the relative weight savings and concurrent cost penalties for several different designs. For the assessment of progress, the 79% steel/21% CFRP structure was selected as it had the best weight savings (30%) while still meeting the DOE cost target of <$11/kg with a projected cost of $8.82/kg. The high composite structure is included for reference, though it is significantly more expensive with a projected cost of $19.58/kg. It is important to note that while much of this cost is from the carbon fiber material, enough is from the manufacturing process such that even if the CF had zero cost, the overall system cost would still exceed the DOE target. This highlights the need for additional research not just in low cost carbon fiber, but in low cost processing and composite fabrication methods.

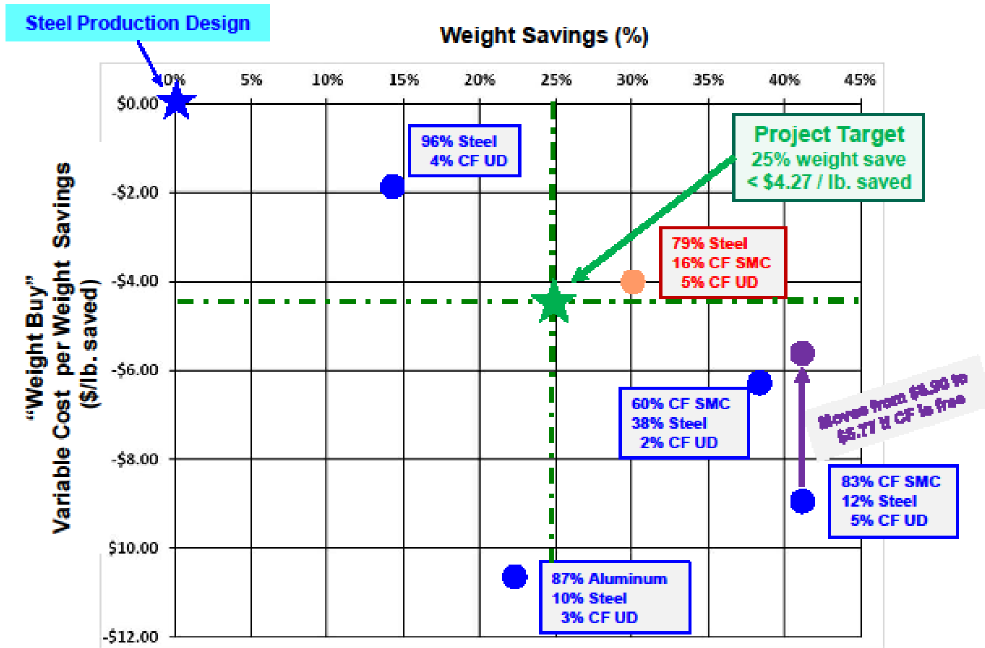

Figure 3: Weight savings and cost for various alternative designs and material compositions [11]

References

1) Joost, W.J. *Reducing Vehicle Weight and Improving U.S. Energy Efficiency Using Integrated Computational Materials Engineering*. JOM 64, 1032–1038 (2012). https://doi.org/10.1007/s11837-012-0424-z
2) U.S Department of Energy, Office of Energy Efficiency and Renewable Energy, *EERE 200.5: Technology Readiness Levels (TRLs)* (n.d.), Retrieved April 28, 2020 https://www.energy.gov/eere/funding/downloads/guidance-documents
3) U.S. Department of Energy, Vehicle Technologies Office. (2016) *Lightweight Materials 2016 Annual Report*, pp. 125-141Retrieved November 19, 2019 https://www.energy.gov/sites/prod/files/2017/11/f46/FY_2016_Lighweight_APR.pdf
4) BASF (2014) *Ultramid Thermoplastic Oil Pan Modules Offer a 45 Percent Weight Reduction - 6 Pound Per Vehicle Savings,* Retrieved Dec 11, 2019 https://automotive.basf.com/news/read/ultramid-thermoplastic-oil-pan-modules-offer-45-percent-weight-reduction-6-pound-per-vehicle-savings
5) Hector, Jr., Louis G., and McCarty, Eric D. *Integrated Computational Materials Engineering Development of Advanced High Strength Steel for Lightweight Vehicles*. United States: N. p., 2017. Web. doi:10.2172/1408097.
6) Hector, Jr., Louis G., *Integrated Computational Materials Engineering Approach to Development of Lightweight 3GAHSS Vehicle Assembly*, U.S. Department of Energy Vehicle Technologies Office 2017 Annual Merit Review and Peer Evaluation Meeting, June 5-9, 2017, Washington, D.C., Retrieved December 9, 2019 https://www.energy.gov/sites/prod/files/2017/06/f34/lm080_hector_2017_o.pdf
7) Coppola, Anthony, Faruque, Omar, Truskin, James F, Board, Derek, Jones, Martin, Tao, Jian, Chen, Yijung, and Mehta, Manish. *Validation of Material Models For Automotive Carbon Fiber Composite Structures Via Physical And Crash Testing (VMM Composites Project).* United States: N. p., 2017. Web. doi:10.2172/1395831.
8) Bushi, L., Skszek, T. & Reaburn, T. *New ultralight automotive door life cycle assessment,* Int J Life Cycle Assess (2019) 24: 310. https://doi.org/10.1007/s11367-018-1515-z
9) Skszek, Timothy. *Ultralight Door Design, Development and Demonstration Project*. United States: N. p., 2019. Web. doi:10.2172/1499668.
10) U.S. Department of Energy, Vehicle Technologies Office. (2018) *Materials 2018 Annual Progress Report*, Retrieved November 18, 2019 https://www.energy.gov/sites/prod/files/2019/04/f62/Final FY-2018 Materials Consolidated Report_compliant.pdf
11) Su, Xuming, Wagner, David, (2019) *Integrated Computational Materials Engineering (ICME) Development of Carbon Fiber Composites for Lightweight Vehicles.* U.S. Department of Energy Vehicle Technologies Office 2019 Annual Merit Review and Peer Evaluation Meeting, June 10-13, 2019, Arlington, VA, Retrieved December 5, 2019 https://www.energy.gov/sites/prod/files/2019/06/f64/mat101_su_2019_o_5.8_11.45am_jl.pdf

Appendix A: DOE Baseline Definition

The baseline vehicle was defined as an average of 16 different mid-size 4 door sedan models from twelve different OEMs that were on sale in 2015. The mass measurements result from teardowns of vehicles in the 2013-2015 model year range that were substantially equivalent to the vehicles on sale in 2015.

Make	Model	MY	Glider Mass [kg]
BMW	328i	2013	991.371
Chevrolet	Malibu 2LT ECOTEC 2.5 DOHC	2014	1064.644
Chevrolet	Malibu Eco 2.4	2013	1053.066
Chrysler	200 C 3.6	2015	1070.535
Ford	Fusion SE 1.6 EcoBoost	2013	1094.224
Ford	Fusion SE Hybrid 2.0	2013	1069.14
Ford	Fusion SE 2.5	2013	1075.527
Honda	Accord Touring V6 3.5	2013	1041.473
Hyundai	Sonata SE 2.4	2015	970.195
Infiniti	Q50 S 3.7 DOHC	2014	1036.661
Lincoln	MKZ 3.7 TIVCT FWD	2013	1156.449
Mazda	Mazda6 i Touring 2.5	2015	972.383
Nissan	Altima 2.5 SL	2013	953.989
Nissan	Altima 2.5 SV	2013	931.047
Toyota	Camry XLE 2.5	2015	1001.586
Volkswagen	Passat 1.4 TSi ACT Comfortline	2015	931.116

The average glider mass, weighted by vehicle sales, is 1015.8 kg (2241 lbs). The glider is defined as the total vehicle minus the powertrain (including fuels and transmission).